Saskatchewan
Ministry of
Agriculture

FINAL REPORT

RESEARCH

ADF

AGRICULTURE DEVELOPMENT FUND

20050724

FEED MANAGEMENT AND PROCESSING OF FLAX TO CONSISTENTLY INCREASE PORK QUALITY AND VALUE

Funded by: The Agriculture Development Fund

August 2009

Prepared by: Prairie Swing Centre Inc. (PSCI)

FEED MANAGEMENT AND PROCESSING FLAX TO CONSISTENTLY INCREASE PORK QUALITY AND VALUE

20050724

Dr. John Patience[1]
Prairie Swine Centre, Inc.
Saskatoon, SK.

Dr. Mike Dugan
Agriculture and Agri-Food Canada
Lacombe, AB

Dr. Ruurd Zijlstra
University of Alberta
Edmonton, AB

Dr. Denise Beaulieu
Prairie Swine Centre, Inc.
Saskatoon, SK

Final Report

August 2009

[1] Present address: Iowa State University, Ames, IA.

ACKNOWLEDGEMENTS

The Saskatchewan Agriculture and Food-Agriculture Development Fund and Flax 2015 are acknowledged for funding the project. Oleet Processing Ltd., Regina, Saskatchewan, Canada is acknowledged for providing the mix of flaxseed and field pea used for the study

Praire Swine Centre, Inc receives strategic funding from Sask Pork, Alberta Pork, the Manitoba pork Council and Saskatchewan Agriculture and Food.

Dr. N. Aldai gratefully acknowledges the receipt of a research contract from the 7th European Community Program (Marie Curie International Outgoing Fellowship). And Dr. M. Juárez acknowledges the receipt of a NSERC fellowship funded through the AAFC ABIP-FOBI program

COLLABORATORS AND CO-INVESTIGATORS

We acknowledge the contribution of: J.L. Aalhus, N. Aldai, K. Erin, J. Fallavollita, I.U. Haq., J.K. Htoo, I. Larsen, P. Leterme, X. Meng, and W. Robertson for the completion of this series of experiments.

INTRODUCTION

This project was the first large-scale research program in Canada to analyze the opportunities of increasing the omega-3 fatty acid content of pork using optimally-processed flaxseed that contains the omega-3 fatty acid, alpha-linolenic. This project built upon attempts to had been made by researchers in the United States, specifically at South Dakota State University (Romans et al. 1995) to incorporate ground flaxseed into corn based diets for grower-finisher pigs.

The feeding of extruded flax in combination with peas has resulted in increased omega-3 fatty acid profiles in pork (Thacker et al. 2004) however, the extrusion was not optimized and nutrient digestibility, which is critical for precision diet formulation was not measured. Corn, in contrast to wheat and barley contain a larger amount of fat, and more of the fat is unsaturated, thus softer. Feeding flaxseed to a barley- or wheat-based diet, as is common in Saskatchewan and Alberta, should result in a carcass fat which is firmer, and therefore less of a challenge during carcass or food processing. Feeding flax to swine has resulted in pork with taste problems (Romans et al. 1995). Apart from the cereal grain that the diet is based on, the amount of time and duration of flax feeding will be important in determining the amount of alpha-linolenic acid that is deposited in the pork. Establishing a correct feeding program for flax will thus be an important first step to create pork with the correct concentration of alpha-linolenic acid to ensure that claims for alpha-linolenic acid content can be made, while ensuring that alpha-linolenic acid in pork does not reach levels unacceptable for taste.

OVERALL RESEARCH PLAN

The project required several experiments, conducted in 3 phases, with overlapping experiments in some cases. The objective of Phase 1 was to determine the digestible content of omega-3 fatty acids and other key nutrients (energy , amino acids) in ground and optimally-processed extruded flax seed. The objective of phase 2 was to develop optimum programs for the feeding of extruded flaxseed in order to achieve desired omega-3 fatty acid enrichments in pork using diets based on typically Western Canadian ingredients.

Phase 3 extended the results of phase 2 to further examine the impact of feeding the extruded flaxseed product on certain costs of production, notably grow-out time. Therefore experiments were conducted feeding the flaxseed for different periods of time, and a final experiment where the flaxseed was fed for the same amount of time, but to pigs differing in starting weight.

PROGRESS

At the time of writing this report all the experiments have been completed to meet the objectives outlined in the proposal. Remaining are some lab assays determining the omega-3 enrichment of the pork for the final experiment. These will be included in a final report. Moreover, two papers have been submitted for publication, one accepted and published, the other pending. These papers describe results for phases 1 and 2 and have been included as part of this report.

Effects of co-extrusion of flaxseed and field pea on the digestibility of energy, ether extract, fatty acids, protein, and amino acids in grower-finisher pigs[1]

J. K. Htoo,[*2] **X. Meng,**[†] **J. F. Patience,**[‡] **M. E. R. Dugan,**[¶] **and R. T. Zijlstra**[*3]

[*]Department of Agricultural, Food and Nutritional Science, University of Alberta, Edmonton, Alberta, Canada T6G 2P5; [†]Food Science and Technology Centre, Alberta Agriculture and Food, Brooks, Alberta, Canada T1R 1E6; [‡]Prairie Swine Centre Inc., Saskatoon, Saskatchewan, Canada S7H 5N9; and [¶]Lacombe Research Centre, Agriculture and Agri-Food Canada, Lacombe, Alberta, Canada T4L 1W1

[1]The Saskatchewan Agriculture and Food-Agriculture Development Fund and Flax 2015 are acknowledged for funding the project. Oleet Processing Ltd., Regina, Saskatchewan, Canada is acknowledged for providing the mix of flaxseed and field pea used for the study.

[2]Present address: Evonik Degussa Canada Inc., P.O. Box 1000, Hwy 643 East, Gibbons, AB, T0A 1N0, Canada.

[3]Corresponding author: ruurd.zijlstra@ualberta.ca

ABSTRACT: The objectives of this study were to determine the ileal and total tract digestibility of individual fatty acids, ether extract, energy, protein, and AA in a mix of flax and field pea (FP) and to determine whether extrusion improves the nutritive value of this mix. Five barrows (23 kg initial BW) fitted with a T-cannula at the distal ileum were fed 5 diets at 3 times the maintenance energy requirement according to a 5 × 5 Latin square design: a wheat and soybean meal control diet and 4 diets containing 30% raw or co-extruded FP plus 70% control diet, and chromic oxide as an indigestible marker. The 4 extrusion treatments included: 1) FP0, ground, non-extruded; 2) FP1, single-screw extruded; 3) FP2, twin-screw extruded with low intensity [screw speed 120 rpm; die temperature 110°C; water input 5 kg/h]; and 4) FP3, twin-screw extruded with high intensity [300 rpm; 125°C; 11 kg/h]. The ether extract concentration was 17.8, 19.6, 17.7, and 17.3% (as-fed) in FP0, FP1, FP2, and FP4, respectively. The ADF concentration was 13.2, 11.1, 11.4, and 13.7% (as-fed) in FP0, FP1, FP2, and FP4, respectively. After a 7-d acclimation, feces were collected for 2 d, and then ileal digesta for 2 d. Energy digestibility in the test ingredients was calculated using the difference method. Extrusion of FP did not affect the apparent total tract digestibility (ATTD) and apparent ileal digestibility (AID) of DM, OM, and CP for grower-finisher pigs. Extrusion increased ($P < 0.05$) the ATTD of GE and ether extract and the DE content of FP, and the AID of the Arg, Ile, Leu, Lys, Phe, Thr, and Val, and total fatty acids. Extrusion tended to increase ($P < 0.10$) the AID of linolenic acid. Single-screw extrusion resulted in a higher ($P < 0.05$) ATTD of GE, OM, ether extract, and DE content of FP and AID of saturated fatty acids than twin-screw extrusion. Single-screw extrusion resulted in a trend for higher ($P < 0.10$) AID of linolenic acid and total fatty acids than twin-screw extrusion. Twin-screw extrusion at high intensity resulted in a lower ($P < 0.05$) AID of saturated fatty acids than twin-screw extrusion at low intensity, indicating that equipment and conditions should be carefully controlled for the extrusion of FP. In conclusion, co-extrusion of flax and field pea increased digestibility of ether extract, fatty acids, energy, and AA.

Key words: digestibility, extrusion, fatty acid, field pea, flax, pig

INTRODUCTION

Increased consumer awareness and demand for dietary omega-3 fatty acids for human health benefits (Simopoulos, 1999; Conners, 2000) has created opportunities for the pork industry to produce omega-3-enriched pork (Bourre, 2005). Flaxseed is a rich source of α-linolenic acid, and feeding pigs diets that contain flaxseed will increase the omega-3 fatty acid content in carcass tissues (Cherian and Sim, 1995; Romans et al., 1995a,b; Matthews et al., 2000).

Feeding of flaxseed poses challenges for grinding and storage because of its high oil and α-linolenic acid content, respectively. Mixing flaxseed with field pea can counteract these problems (Thacker et al., 2004). A flax and field pea mix (**FP**) can be used as a source of energy, AA, and omega-3 fatty acids in pig diets; however, flaxseed and field pea contain anti-nutritional factors. Flaxseed contains mucilage, phytic acid, goitrogens, allergens, and anti-pyridoxin (Madhusudhan et al., 1986). Field pea contains protease inhibitors, lectins, and tannins (O'Doherty and Keady, 2000). To inactivate these compounds, FP can be processed using heat, e.g., extrusion (Melcion and Van der Poel, 1993). Positive effects of extrusion are reductions in trypsin inhibitor activity and tannin content in field pea (O'Doherty and Keady, 2000). The hypothesis of the present study was that co-extrusion of flaxseed and field pea will improve digestibility of nutrients, and that the selected extrusion technology (single- vs. twin-screw) and conditions (high vs. low intensity) may impact nutrient digestibility (Riaz, 2001).

The objectives of this study were to determine the ileal and total tract digestibility of individual fatty acids, ether extract, energy, protein, and AA in FP and to determine whether extrusion alters the nutritive value of this mix. An additional objective was to compare nutrient and energy digestibility of diets containing 30% FP with a conventional diet.

MATERIALS AND METHODS

Ingredients and Extrusion Processing

A 50:50 (wt/wt) mix of FP was obtained (Oleet Processing Ltd., Regina, Saskatchewan, Canada). The mix was divided into 4 portions that were processed separately (Table 1): 1) FP0, ground through a knife mill with a 2-mm sieve, non-extruded; 2) FP1, extruded using a single-screw extruder with minimal water input; 3) FP2, extruded using a twin-screw extruder at low intensity; and 4) FP3, extruded using a twin-screw at high intensity. The single-screw extruder (Model 600, Insta-Pro Int., Des Moines, IA) was located at a commercial company (FP1: commercially sold as LinPRO; Oleet Processing Ltd., Regina, Saskatchewan, Canada. The twin-screw extruder (Model ZSK 57-M 50/2, Werner & Pfleiderer, Stuttgart, Germany) was located at the Food Science and Technology Centre of Alberta Agriculture and Food (Brooks, Alberta, Canada).

Experimental Design and Diets

The basal and FP-diets were based on wheat and soybean meal (Table 2). The 4 FP-diets were formulated by replacing 30% of the basal diet with 1 of the 4 FP treatments so that all experimental diets were not limiting in AA. Canola oil, vitamins, and minerals were supplemented in the diets to supply all nutrients and energy according to NRC (1998) standards. Chromic oxide (0.3%) was included in the diets as an indigestible marker.

Experimental Protocols

The animal protocol for the study was approved by the University of Alberta Faculty Animal Policy and Welfare Committee, and followed established principles (CCAC, 1993). The experiment was conducted at the Swine Research and Technology Centre of the University of Alberta (Edmonton, Alberta, Canada).

Five crossbred barrows (Duroc × Large White/Landrace; Genex Hybrid; Hypor, Regina, Saskatchewan, Canada; initial BW, 23.1 kg) were housed individually in steel metabolism pens (height, 1.1 m; length, 2.4 m; width, 1.5 m) that allowed freedom of movement in a temperature-controlled room (20 ± 1°C). Each pen was equipped with a single-hole feeder and a low-pressure drinking nipple. Pigs

were fitted with a T-cannula at the distal ileum (Sauer et al., 1983). Pigs were fed a 20% CP pre-grower diet that did not contain flaxseed or field pea during the adaptation period to the pens and the 10-d recuperation from surgery.

Following recuperation from surgery, pigs were randomly assigned to 1 of 5 experimental diets according to a 5 × 5 Latin square design in 1 of five 11-d experimental periods. Daily feed allowance was adjusted to 3 times the maintenance energy requirement (3 x 110 kcal DE/kg $BW^{0.75}$; NRC, 1998) based on the average BW at the start of each experimental period. The feed was fed in 2 equal meals at 0800 and 1500. The diets were fed as a mash. Pigs had free access to water.

The experimental periods consisted of a 7-d acclimation to experimental diets, followed by a 2-d collection of feces, and then a 2-d collection of ileal digesta. Feces were collected from 0800 to 1800. Ileal digesta were collected from 0800 to 2000 into plastic bags (length, 10 cm; diameter, 4 cm) that contained 8 mL of 10% (vol/vol) formic acid to minimize bacterial fermentation. Bags were removed when digesta filled approximately half of the bag. Collected feces and digesta were pooled by pig and period and immediately frozen at –28°C. Feces and digesta were freeze-dried prior to analyses.

Chemical Analysis

Feed, FP, and freeze-dried feces and digesta were ground through a 0.5-mm screen and analyzed for DM, ether extract, and ash (AOAC, 2006). Gross energy was analyzed by an adiabatic bomb calorimeter (AC-300 Automatic Calorimeter, Leco Corporation, St. Joseph, MI) and N was analyzed by combustion (method 968.06; AOAC, 2006) using an N Analyzer (FP-428, Leco Corporation, St. Joseph, MI).

Feed, feces, and digesta samples were analyzed for Cr_2O_3 by spectrophotometry at 440 nm after ashing at 450°C overnight (Fenton and Fenton, 1979). Feed, FP, and digesta samples were analyzed for all AA, except Met, Cys, and Trp, by HPLC (Liao et al., 2005), and for fatty acids by GLC (Sukhija and Palmquist, 1988). The 4 FP samples were analyzed for Ca, P, K, Mg, and Na (atomic emission spectrophotometry; AOAC, 2006), ADF (method 973.18; AOAC, 2006), NDF (Van Soest et al., 1991), and available Lys (method 975.44; AOAC, 2006). Analyses were carried out in duplicate.

Calculations and Statistical Analysis

Based on the results of the chemical analyses, apparent ileal digestibility of AA, fatty acids, ether extract, DM, OM, CP, and GE and the total tract digestibility of ether extract, DM, OM, CP, and GE were calculated using the Cr_2O_3 concentration of feed, digesta, and feces (Adeola, 2001). The digestibility coefficients of the 4 FP sources were separated from the basal diet using the difference method (Fan and Sauer, 1995). The DE content was calculated using the GE content multiplied by the digestibility coefficient for GE.

To compare differences among treatments, data were subjected to ANOVA as a 5 × 5 Latin Square design using the GLM procedure of SAS (SAS Inst. Inc., Cary, NC). The fixed effect of diet (n = 5) and the random effect of experimental period (n = 5) and animals (n = 5) were included in the model. The pig was used as the experimental unit and means were reported as least-square means. Treatment means were compared using preplanned contrasts. Differences were considered significant if $P < 0.05$ and were described as tendencies if $0.05 < P < 0.10$.

RESULTS

All pigs remained healthy and readily consumed their daily allowances throughout the experiment. Intestinal adhesions were not observed during postmortem examinations at the end of the experiment. The average BW of the pigs was 31.8, 37.7, 43.7, 50.9, and 57.3 kg at the start of experimental periods 1, 2, 3, 4, and 5, respectively, and 67.7 kg at the end of the experiment.

Main Constituent Composition

FP Sources. In the 4 FP samples, slight variations in the GE, AA, and ADF composition occurred (Table 3). The concentration of NDF was 3 to 5% lower in the 3 extruded FP samples than the ground and not extruded FP. The total and available Lys concentrations did not differ among the 4 FP samples.

Diets. The analyzed nutrient composition of the 5 diets is reported in Table 4. Results indicate that the NRC (1998) standards for energy, CP, and AA of grower-pigs were met or exceeded.

Main Constituent Digestibility

Diets. The apparent ileal digestibility (**AID**) of DM, OM, CP, and GE was higher ($P < 0.001$) in the basal diet than the 4 FP diets (Table 5). The AID of energy and nutrients was not different among the FP diets. The apparent total tract digestibility (**ATTD**) of DM, OM, CP, and GE was higher ($P < 0.001$) in the basal diet than the 4 FP diets. The ATTD of GE was lower ($P < 0.05$) in the diet containing ground and not extruded FP and tended to be lower ($P = 0.10$) for OM than the 3 diets containing extruded FP. The diet containing FP extruded using a single-screw extruder had a higher ($P < 0.01$) GE digestibility and a higher ($P < 0.05$) OM digestibility than the 2 diets containing FP extruded using a twin-screw extruder. The diet containing FP extruded using a twin-screw extruder at high intensity had higher ($P < 0.05$) CP digestibility than the diet containing FP extruded using a twin-screw extruder at low intensity.

FP Sources. The ileal DE content tended to be higher ($P < 0.10$) in the 3 extruded FP sources than the ground and not extruded FP (Table 6). Differences in AID of energy and nutrients were not observed. The ATTD of GE ($P < 0.05$) and the DE content ($P < 0.01$) of ground and not extruded FP was lower than of the 3 extruded FP sources. The DE content and ATTD of GE and OM were higher ($P < 0.05$) in FP extruded using a single-screw extruder than the 2 FP extruded using a twin-screw extruder. The FP extruded using a twin-screw extruder at high intensity tended to have a higher ($P < 0.10$) CP digestibility than the FP extruded using a twin-screw extruder at low intensity.

AA Digestibility

Diets. The AID was higher ($P < 0.05$) for Arg, His, Ile, Leu, Phe, Thr, and Val in the basal diet than in the 4 FP diets (Table 7). Among the AA, the AID of the basal diet was 89.6% for Lys and 81.3% for Thr. The AID of the diet containing ground and not extruded FP was lower ($P < 0.05$) for Arg, Ile, Leu, Lys, Phe, Thr, and Val and tended to be lower ($P < 0.10$) for His than of the 3 diets containing extruded FP. The AID of AA was not different for the diet containing FP extruded using a single-screw extruder compared with the 2 diets containing FP extruded using a twin-screw extruder. The AID of the diet containing FP extruded using a twin-screw extruder at high intensity was higher ($P < 0.05$) for His than the diet containing FP extruded using a twin-screw extruder at low intensity.

FP Sources. The AID of Arg, Ile, Leu, Lys, Phe, Thr, and Val was higher ($P < 0.05$) and tended to be higher ($P < 0.10$) for His in the 3 extruded FP sources than ground and not extruded FP (Table 8). The AID of AA was not different for FP extruded using a single-screw extruder compared with the 2 FP extruded using a twin-screw extruder.

Fatty Acid Composition

FP Sources. The concentration of fatty acids was slightly higher in ground and not extruded FP than the 3 extruded FP sources (Table 9). As expected, the concentration of linolenic acid (C18:3) ranged from 49.6 to 51.1% as a percentage of total fatty acids, and linolenic acid had the highest concentration of the fatty acids in each of the 4 FP sources. The fatty acid profiles, expressed as % of total fatty acids, were similar among the 4 FP sources.

Diets. The total fatty acid concentration in the 4 FP diets ranged from 6.5 to 7.9% (as-fed) and compared to 2.7% in the basal diet (Table 10). In the 4 FP diets, linolenic acid was the fatty acid with the highest concentration.

Fatty Acid Digestibility

Diets. The AID of the fatty acids, palmitic, arachidic, oleic, vaccenic, linoleic, and linolenic, and saturated, unsaturated, and total fatty acids was higher ($P < 0.05$; Table 11) in the basal diet than the FP diets, and tended to be higher ($P < 0.10$) for stearic and ether extract. The AID of the diet containing ground and not extruded FP was lower ($P < 0.05$) for palmitic, stearic, arachidic, oleic, vaccenic, linolenic acids, and saturated, unsaturated, and total fatty acids and tended to be lower ($P < 0.10$) for linoleic acid and ether extract than of the 3 diets containing extruded FP. The ATTD of ether extract was lower ($P < 0.001$) in the diet containing ground and not extruded FP than of the 3 diets containing extruded FP. The diet containing FP extruded using a single-screw extruder had a higher ($P < 0.05$) AID of palmitic, stearic, arachidic, oleic, vaccenic, linolenic, and of saturated, unsaturated, and total fatty acids than the 2 diets containing FP extruded using a twin-screw extruder, and a higher ATTD of ether extract ($P < 0.01$). The diet containing FP extruded using a twin-screw extruder at low intensity had a higher ($P < 0.05$) AID of stearic, arachidic, oleic, vaccenic, and SFA, and tended to have a higher AID of palmitic acid ($P < 0.10$) than the diet containing FP extruded using a twin-screw extruder at high intensity

FP Sources. The AID and ATTD of the fatty acids in the 4 FP sources (Table 12) mimicked the differences observed in the FP diets. In ground and not extruded FP, the AID of SFA and ATTD of ether extract was lower ($P < 0.01$) and the AID of unsaturated fatty acid tended to be lower ($P < 0.10$) than of the 3 extruded FP sources. The AID of SFA and ATTD of ether extract in FP extruded using a single-screw extruder was higher ($P < 0.01$) than in the 2 FP extruded using a twin-screw extruder. The AID of SFA was higher ($P < 0.05$) in FP extruded using a twin-screw extruder at low intensity than FP extruded using a twin-screw extruder at high intensity.

DISCUSSION

Little information exists on the composition of flax products and their digestibility of nutrients (including omega-3 fatty acids) and energy of flax products in swine. The present study was, therefore, conducted to determine the digestibility of fatty acids, ether extract, energy, protein, and AA in a flax-field pea mix fed to grower-finisher pigs. To enhance nutrient digestibility, flax and field pea were co-extruded, similar to co-extrusion of full-fat canola seed and field pea (Kiarie and Nyachoti, 2006). Flax is an oilseed containing 35% ether extract, and field pea is a legume seed containing around 22% CP and 41% starch (CVB, 1994). Co-extrusion of flax and field pea, therefore, allows the blending of macronutrients, and single extrusion of flax might produce a product with undesirable handling characteristics due to the released oil. Extrusion might improve nutrient digestibility because of cell wall disruption and the potential inactivation of heat-labile anti-nutritional factors in flax and field pea (Harper, 1978).

The effects of extrusion on DM and CP digestibility are not consistent among studies with swine. The extrusion of FP did not affect the AID or ATTD of DM, OM, and CP for pigs in the present study. In a previous study, extrusion did not affect ATTD of CP and increased ATTD of OM of a field pea-diet fed to grower-finisher pigs (O'Doherty and Keady, 2001). Similarly, extrusion of corn did not affect the ATTD and AID of CP and indispensable AA for 20-kg pigs (Herkelman et al., 1990). In a recent study, extrusion did not affect the AID of total AA of corn in grower pigs (Muley et al., 2007). In contrast, extrusion increased the AID of CP of field pea with a high trypsin inhibitor activity (Mariscal-Landín et al., 2002). Extrusion of a cereal and soybean meal-based diet improved the ATTD of DM and CP in early-weaned pigs compared with pelleting (Sauer et al., 1990). Extrusion is supposed to inactivate heat-labile anti-nutritional factors in feedstuffs and improve CP digestibility and increase starch gelatinization, and improve OM digestibility (O'Doherty and Keady, 2001; Mariscal-Landín et al., 2002). However, proteins in feedstuffs are temperature-sensitive. Under the influence of heat, proteins may denature, coagulate, or form Maillard reaction products. Protein denaturation generally has a neutral effect on CP digestibility for balanced diets for monogastric animals (Peisker, 1992).

Extrusion improved the AID of AA in the FP in the present study. A substantial amount of Lys may be lost due to condensation between ε-NH_2 of Lys and C = O of reducing sugars when legume or cereal legume blends are extruded under high temperature or shear force conditions at a low moisture content (Björck and Asp, 1983). The AID analysis of AA has limitations for heat-processed feedstuffs, especially

for Lys with extensive heat (Van Barneveld et al., 1995). However, the content of available and, thus, intact Lys and the AID of Lys were identical among the 4 FP samples, indicating that extrusion did not damage the Lys in the FP in the present study.

Extrusion of FP improved the ATTD but not the AID of ether extract in the present study, similar to previous work that indicated that the extrusion of corn improved the ATTD but not the AID of ether extract in 20-kg pigs (Herkelman et al., 1990). In the present study, the variability among the treatment means was higher for the AID than the ATTD coefficients, contributing to less chance of treatment separation of AID coefficients. The higher AID, observed for unsaturated fatty acids compared with SFA, is consistent with previous research (Overland et al., 1993). Similar to ether extract, extrusion enhanced the AID of fatty acids in FP. Improved ether extract digestibility caused by extrusion is mainly due to the disruption of fat globules because of the shearing effect of the screw on the lipid structures, thereby, providing easier access for lipase enzymes in the digestive tract (Hancock and Behnke, 2001). Single-screw extrusion of FP resulted in a higher AID for fatty acids than twin-screw extrusion, indicating that knowledge of the optimum extrusion equipment and conditions to achieve maximum digestibility of fatty acids is important (Serrano, 1997). Maximum shear stress to disrupt the lipid structures in the FP likely occurred with the single-screw extruder in the present study (Riaz, 2001), thereby, explaining the highest AID or ATTD for fatty acids and ether extract. Shear in the twin-screw extruder was further reduced in FP extruded using a twin-screw extruder at high intensity compared with FP extruded using a twin-screw extruder at low intensity. The difference was, perhaps, a reflection of the reduced screw torque because of extra water addition to FP extruded using a twin-screw extruder at high intensity, thereby, reducing the uplift in its fatty acid digestibility. Extent of both shear and processing temperature might, thus, be important to maximize digestibility of ether extract and fatty acids in FP. Based on our results, ground and single-screw-extruded FP can provide 54.9 and 61.3 g of digestible omega-3 fatty acid/kg of FP for grower-finisher pigs, respectively.

In swine feed formulation, energy content is the greatest cost factor (Zijlstra et al., 2001). In the present study, extrusion increased energy digestibility, especially for single-screw extrusion. Single-screw extrusion increased the ATTD of GE by 11% and the DE content from 3.70 to 4.35 Mcal/kg (DM basis). Extrusion reduced the content of NDF in flax-field pea mixes in the present study, indicating that extrusion modifies the physico-chemical properties of fiber via partial solubilization or degradation (Björck et al. 1984), an important finding because of the inverse relationship between fiber content and energy digestibility (Zijlstra et al., 1999). Extrusion improved the energy digestibility of cereal grains for grower pigs (Noland et al., 1976; Herkelman et al., 1990; O'Doherty and Keady, 2001) and flax-field pea mix for broiler chicken (Thacker et al., 2005). Extrusion processing improved the digestibility of the important energy-yielding nutrient, starch, in corn fed to piglets (Van der Poel et al., 1989). The impact of extrusion on digestibility of the energy-yielding nutrient with the highest energy content, i.e., fat, was already discussed. As a result of extrusion, the nutrient and fiber fractions might become more accessible to digestion or fermentation in the gastro-intestinal tract, resulting in increased energy digestibility (Marty et al., 1994; O'Doherty and Keady, 2000). Twin-screw extrusion of FP compared with single-screw extrusion did not increase in the ATTD of GE, ether extract, and some fatty acids. Contributing factors to temperature and shear of the product during extrusion such as water and steam input, temperature, screw speed, and pressure, should be carefully managed (Serrano, 1997) to ensure that excess processing is avoided.

The inclusion of a regular grower pig diet as a basal diet in the experiment allowed for comparisons between diets containing FP and a typical swine diet. The AID and ATTD of DM, OM, CP, and GE, and the AID of the majority of AA and fatty acids, and ether extract were higher in the basal diet that contained wheat and soybean meal than in the FP-containing diets. The reduced nutrient digestibility of diets containing FP is, thus, clearly an ingredient effect that might be due to anti-nutritional factors such as the higher fiber content in the raw flax-field pea mix (O'Doherty and Keady, 2000; Madhusudhan et al., 1986) that may increase digesta viscosity and leads to reduced nutrient digestibility (Bell and Keith, 1993). The negative effects, in particular for the digestibility of ether extract and fatty acids, and some AA, may be moderated by extruding the flax-field pea mix. Ground flax can be included up to 15% in pig

diets without detrimental effects on growth performance (Romans et al., 1995a,b); however, data from the present study indicates that extrusion enhances nutrient digestibility of flax. Co-extruded flax will, therefore, be used in future experiments at our laboratories to study the impact of extruded flax on omega-3 fatty acid profile in pork.

In conclusion, extrusion of flax-field pea mix improved the digestibility of ether extract, energy, AA, and some fatty acids, and, thereby, increased the content of DE and omega-3 fatty acids. Extrusion technologies should be considered to optimize feeding programs for omega-3 enriched pork. The extruded flax-field pea mix can be used as a source of energy and AA at the inclusion rate used in the present study.

LITERATURE CITED

Adeola, O. 2001. Digestion and balance techniques in pigs. Pages 903–916 in Swine Nutrition. 2nd ed. A. J. Lewis and L. L. Southern, ed. CRC Press, Boca Raton, FL.

AOAC. 2006. Official Methods of Analysis. 18th ed. Assoc. Off. Anal. Chem., Gaithersburg, MD.

Bell, J. M., and M. O. Keith. 1993. Nutritional evaluation of linseed meals from flax with yellow or brown hulls, using mice and pigs. Anim. Feed Sci. Technol. 43:1–18.

Björck, I., and N. G. Asp. 1983. The effects of extrusion-cooking on nutritional value. A literature review. J. Food Eng. 2:281–308.

Björck, I., M. Nyman, and N. G. Asp. 1984. Extrusion-cooking and dietary fiber: Effects on dietary fiber content and on degradation in the rat intestinal tract. Cereal Chem. 61:174–179.

Bourre, J. M. 2005. Where to find omega-3 fatty acids and how feeding animals with diet enriched in omega-3 fatty acids to increase nutritional value of derived products for human: what is actually useful? J. Nutr. Health Aging. 9:232–242.

CCAC. 1993. Guide to the Care and Use of Experimental Animals. Vol. 1. 2nd ed. Can. Coun. Anim. Care, Ottawa, Ontario, Canada.

CVB. 1994. Veevoedertabel (Table of nutritional value of feed ingredients). Centraal Veevoederbureau, Lelystad, The Netherlands.

Cherian, G., and J. S. Sim. 1995. Dietary α-linolenic acid alters the fatty acid composition of lipid classes in swine tissues. J. Agric. Food Chem. 43:2911–2916.

Conners, W. E. 2000. Importance of n-3 fatty acids in health and disease. Am. J. Clin. Nutr. 71:171S–175S.

Fan, M. Z., and W. C. Sauer. 1995. Determination of apparent ileal amino acid digestibility in barley and canola meal for pigs with the direct, difference, and regression methods. J. Anim. Sci. 73:2364–2374.

Fenton, T. W., and M. Fenton. 1979. An improved procedure for the determination of chromic oxide in feed and feces. Can. J. Anim. Sci. 59:631–634.

Hancock, J. D., and K. C. Behnke. 2001. Use of ingredient and diet technologies (grinding, mixing, pelleting, and extruding) to produce quality feeds for pigs. Pages 469–492 in Swine Nutrition. 2nd ed. A. J. Lewis and L. L. Southern, ed. CRC Press, Boca Raton, FL.

Harper, J. M. 1978. Food extrusion. Crit. Rev. Food Sci. Nutr. 11:155–215.

Herkelman, K. L., S. L. Rodhouse, T. L. Veum, and M. R. Ellersieck. 1990. Effect of extrusion on the ileal and fecal digestibilities of lysine in yellow corn in diets for young pigs. J. Anim. Sci. 68:2414–2424.

Kiarie, E., and C. M. Nyachoti. 2006. Ileal digestibility of amino acids in co-extruded peas and full fat canola for growing pigs. Anim. Feed Sci. Technol. 139:40–51.

Liao, S., A. Kies, W.C. Sauer, Y. Zhang, M. Cervantes, and J. M. He. 2005. Effect of phytase supplementation to a low- and high- phytate diet for growing pigs on the digestibilities of crude protein, amino acids, and energy. J. Anim. Sci. 83:2130–2136.

Madhusudhan, K. I., H. P. Ramesh, T. Ogawa, K. Sasaoka, and N. Singh. 1986. Detoxification of commercial linseed meal for use in broiler rations. Poult. Sci. 65:164–171.

Mariscal-Landín, G., Y. Lebreton, and B. Sève. 2002. Apparent and standardized true ileal digestibility of amino acids from faba bean, lupin and pea, provided as whole seeds, dehulled or extruded in pig diets. Anim. Feed Sci. Technol. 97:183–198.

Marty, B. J., E. R. Chavez, and C. F. M. De Lange. 1994. Recovery of amino acids at the distal ileum for determining apparent and true ileal amino acid digestibilities in growing pigs fed various heat-processed full-fat soybean products. J. Anim. Sci. 72:2029–2037.

Matthews, K. R., D. B. Homer, F. Thies, and P. C. Calder. 2000. Effect of whole linseed (Linum usitatissimum) in the diet of finishing pigs on growth performance and on the quality and fatty acid composition of various tissues. Br. J. Nutr. 83:637–643.

Melcion, J.-P., and Van der Poel, A.F.B. 1993. Process technology and antinutritional factors: Principles, adequacy and process optimization. Pages 419–434 in EAAP Publication Recent Advances of Research in Antinutritional Factors in Legume Seeds, A. F. B. Van der Poel, J. Huisman, and H. S. Saini, eds. Wageningen Academic Press, Wageningen, The Netherlands.

Muley, N. S., E. van Heugten, A. J. Moeser, K. D. Rausch, and T. A. T. G. van Kempen. 2007. Nutritional value for swine of extruded corn and corn fractions obtained after dry milling. J. Anim. Sci. 85:1695–1701.

NRC. 1998. Nutrient Requirements of Swine. 10th rev. ed. Natl. Acad. Press, Washington, DC.

Noland, P. R., D. R. Campbell, R. K. Gage, Jr., R. N. Sharp, and Z. B. Johnson. 1976. Evaluation of processed soybeans and grains in diets for young pigs. J. Anim. Sci.43:763–769.

O'Doherty, J. V., and U. Keady. 2000. The nutritive value of extruded and raw peas for growing and finishing pigs. Anim. Sci. 70:265–274.

O'Doherty J. V., and U. Keady. 2001. The effect of expander processing and extrusion on the nutritive value of peas for pigs. Anim. Sci. 72:43–53.

Overland, M., M. D. Tokach, S. G. Cornelius, J. E. Pettigrew, and J. W. Rust. 1993. Lecithin in swine diets: I. Weanling pigs. J. Anim. Sci. 71:1187–1193.

Peisker, M. 1992. Futtermittelmodifizierung beim Expandieren. Pages 178–186 in Internationale Tagung Schweine und Geflügelernährung, Offset Köhler KG, Giesen-Wieseck, Germany.

Riaz, M. N. 2001. Selecting the right extruder. Pages 29–50 in Extrusion Cooking: Technology and Application, R. Guy, ed. CRC Press, Cambridge, UK.

Romans, J. R., R. C. Johnson, D. M. Wulf, G. W. Libal, and W. J. Costello. 1995a. Effects of ground flaxseed in swine diets on pig performance and on physical and sensory characteristics and omega-3 fatty acid content of pork: I. Dietary level of flaxseed. J. Anim. Sci. 73:1982–1986.

Romans, J. R., D. M. Wulf, R. C. Johnson, G. W. Libal, and W. J. Costello. 1995b. Effects of ground flaxseed in swine diets on pig performance and on physical and sensory characteristics and omega-3 fatty acid content of pork: II. Duration of 15% dietary flaxseed. J. Anim. Sci. 73:1987–1999.

Sauer, W. C., R. Mosenthin, and A. B. Pierce. 1990. The utilization of pelleted, extruded, and extruded and repelleted diets by early weaned pigs. Anim. Feed Sci. Technol. 31:269–275.

Serrano, X. 1997. The extrusion-cooking process in animal feeding. Nutritional implications. Pages 107–114 in Feed Manufacturing in Southern Europe: New Challenges, P. Morand-Fehr, ed. CIHEAM-IAMZ, Zaragoza, Spain.

Simopoulos, A.P. 1999. Essential fatty acids in health and chronic disease. Am. J. Clin. Nutr. 70:560S–569S.

Sukhija, P. S., and D. L. Palmquist. 1988. Rapid method for the determination of total fatty acid content and composition of feedstuffs and feces. J. Agric. Food Chem. 36:1202–1206.

Thacker, P. A., V. J. Racz, and H. W. Soita. 2004. Performance and carcass characteristics of growing-finishing pigs fed barley-based diets supplemented with Linpro (extruded whole flaxseed and peas) or soybean meal. Can. J. Anim. Sci. 84:681–688.

Thacker, P. A., B. P. Willing, and V. J. Racz. 2005. Performance of broiler chicks fed wheat-based diets supplemented with combinations of non-extruded or extruded canola, flax and peas. J. Anim. and Vet. Advances 4:902–907.

Van Barneveld, R. J., E. S. Batterham, and D. C. Skingle. 1995. The effect of heat on amino acids for growing pigs 4. Nitrogen balance and urine, serum and plasma composition of growing pigs fed on raw or heat-treated field peas (Pisum sativum). Br. J. Nutr. 73:259–273.

Van der Poel, A. F. B, L. A. den Hartog, T. van den Abeele, H. Boer, and D. J. Van Zuilichem. 1989. Effect of infrared irradiation or extrusion processing of maize on its digestibility in piglets. Anim. Feed Sci. Technol. 26:29–43.

Van Soest, P. J., J. B. Robertson, and B. A. Lewis. 1991. Symposium: Carbohydrate methodology, metabolism and nutritional implications in dairy cattle. Methods for dietary fiber, neutral detergent fiber, and non-starch polysaccharides in relation to animal nutrition. J. Dairy Sci. 74:3583–3597.

Zijlstra, R. T., C. F. M. de Lange, and J. F. Patience. 1999. Nutritional value of wheat for growing pigs: Chemical composition and digestible energy content. Can. J. Anim. Sci. 79:187–194.

Zijlstra, R. T., E. D. Ekpe, M. N. Casano, and J. F. Patience. 2001. Variation in nutritional value of western Canadian feed ingredients for pigs. Pages 12–24 in Proc. 22nd Western Nutr. Conf., Saskatoon, SK. Univ. of Saskatchewan, Saskatoon, Saskatchewan, Canada.

Table 1. Extrusion conditions of the co-extruded 50:50 flaxseed-field pea (FP)

	Co-extruded flaxseed-field pea[1]		
Extrusion conditions	FP1	FP2	FP3
Extruder type	single-screw	twin-screw	twin-screw
Screw speed, rpm	-	120	300
Screw torque, %	-	60 to 70	26
Pressure, kPa	2,750	-	-
Water input, kg/h	0	5	11
Steam input, kg/h	-	100	150
Barrel temperature at cooking zone, °C	135	100	135
Die temperature, °C	-	110	125

[1]FP1, FP2, and FP3 was a 50:50 flaxseed-field pea mix extruded as follows: FP1, extruded using single-screw extruder; FP2, extruded using twin-screw extruder at low intensity; and FP3, extruded using twin-screw extruder at high intensity.

Table 2. Ingredient composition (as-fed basis) of the basal and flaxseed-field pea (FP) diets

Ingredient, %	Basal diet	FP diets[1]
Wheat	71.96	49.40
50:50 flaxseed and field pea	-	30.00
Soybean meal	21.93	15.05
Canola oil	1.79	1.23
Mineral-vitamin premix[2]	4.00	4.00
Ethoxyquin[3]	0.02	0.02
Chromic oxide	0.30	0.30

[1]Diet FP0, FP1, FP2, and FP3, each contained 30% of a 50:50 flaxseed-field pea mix processed as follows: FP0, ground and not extruded; FP1, extruded using single-screw extruder; FP2, extruded using twin-screw extruder at low intensity; and FP3, extruded using twin-screw extruder at high intensity.

[2]Provided the following per kilogram of diet: Na, 3.18 g as salt; Cl, 4.90 g as salt; Fe, 214 mg as ferrous sulfate; Zn, 107 mg as zinc carbonate; Mn, 48.6 mg as manganese sulfate; Cu, 124 mg as copper sulfate; I, 0.36 mg as potassium iodate; Co, 0.06 mg as cobalt sulfate; Se, 0.054 mg as sodium selenite; vitamin A, 8,928 IU; vitamin D_3, 992 IU; vitamin E, 71.2 IU; vitamin K_3, 0.62 mg; vitamin B_{12}, 0.02 mg; riboflavin, 5 mg; niacin, 22 mg; D-pantothenic acid, 15 mg; biotin, 0.09 mg; and choline, 260 mg.

[3]Provided 132 mg of ethoxyquin per kilogram of diet.

Table 3. Analyzed nutrient, energy and AA composition (as-fed basis) of the co-extruded 50:50 flaxseed-field pea (FP)

	Co-extruded flaxseed-field pea[1]			
Nutrient	FP0	FP1	FP2	FP3
Dry matter, %	90.95	94.90	91.30	88.99
Gross energy, Mcal/kg	4.83	5.12	5.02	4.87
Organic matter, %	87.30	91.22	87.69	85.57
Ether extract, %	17.75	19.59	17.74	17.27
Neutral detergent fiber, %	24.50	18.80	21.60	20.10
Acid detergent fiber, %	13.20	11.10	11.40	13.70
Ash, %	3.65	3.68	3.61	3.42
Crude protein, %	22.60	22.73	22.10	21.43
Calcium, %	0.16	0.18	0.16	0.16
Phosphorus, %	0.43	0.43	0.43	0.41
Indispensable AA, %				
Arg	1.46	1.51	1.55	1.52
His	0.42	0.44	0.45	0.43
Ile	0.78	0.82	0.82	0.81
Leu	1.20	1.26	1.26	1.23
Lys	1.04	1.08	1.07	1.03
Phe	0.85	0.90	0.90	0.89
Thr	0.77	0.81	0.89	0.88
Val	0.84	0.89	0.89	0.88
Available Lys	0.94	0.97	1.00	0.95

[1]FP0, FP1, FP2, and FP3 was a 50:50 flaxseed-field pea mix processed as follows: FP0, ground and not extruded; FP1, extruded using single-screw extruder; FP2, extruded using twin-screw extruder at low intensity; and FP3, extruded using twin-screw extruder at high intensity.

Table 4. Analyzed nutrient, energy and AA composition (as-fed basis) of the experimental diets

	Diets[1]				
Item	Basal	FP0	FP1	FP2	FP3
Dry matter, %	88.91	89.21	90.24	89.04	89.11
Gross energy, Mcal/kg	3.88	4.13	4.14	4.27	4.15
Organic matter, %	82.63	82.66	83.52	84.54	82.50
Ether extract, %	2.68	7.43	8.54	8.69	7.15
Ash, %	6.28	6.56	6.73	6.50	6.61
Crude protein, %	22.44	22.05	19.74	18.48	21.10
Indispensable AA, %					
Arg	0.89	1.02	1.04	0.95	1.02
His	0.45	0.40	0.40	0.35	0.42
Ile	0.67	0.68	0.70	0.64	0.68
Leu	1.15	1.13	1.15	1.07	1.13
Lys	0.96	0.99	0.99	0.98	0.98
Phe	0.78	0.77	0.80	0.75	0.78
Thr	0.65	0.68	0.65	0.64	0.68
Val	0.69	0.71	0.74	0.68	0.71

[1]Diet FP0, FP1. FP2, and FP3, each contained 30% of a 50:50 flaxseed-field pea mix processed as follows: FP0, ground and not extruded; FP1, extruded using single-screw extruder; FP2, extruded using twin-screw extruder at low intensity; and FP3, extruded using twin-screw extruder at high intensity.

Table 5. The apparent ileal and total tract digestibility of DM, OM, CP, and GE of the experimental diets

Item	Diets[1]					SEM	*P*-value[2]			
	Basal	FP0	FP1	FP2	FP3		Basal vs. FP	FP0 vs. FP1, 2, and 3	FP1 vs. FP2 and 3	FP2 vs. FP3
Ileal digestibility, %										
DM	79.2	75.2	75.5	76.9	75.7	0.6	< 0.001	0.259	0.293	0.200
OM	81.2	77.1	77.7	78.8	77.6	0.6	< 0.001	0.177	0.477	0.143
CP	86.9	83.0	83.7	83.2	84.5	0.6	< 0.001	0.269	0.819	0.183
GE	82.1	76.8	78.0	78.3	78.2	0.7	< 0.001	0.129	0.737	0.889
Total tract digestibility, %										
DM	86.6	83.1	84.7	83.8	83.5	0.6	< 0.001	0.205	0.169	0.675
OM	88.9	85.2	87.1	85.8	85.8	0.5	< 0.001	0.100	0.048	0.996
CP	86.7	84.4	83.5	82.9	85.3	0.6	< 0.001	0.418	0.385	0.012
GE	86.8	80.8	84.5	82.3	81.9	0.6	< 0.001	0.013	0.009	0.668

[1]Diet FP0, FP1, FP2, and FP3, each contained 30% of a 50:50 flaxseed-field pea mix processed as follows: FP0, ground and not extruded; FP1, extruded using single-screw extruder; FP2, extruded using twin-screw extruder at low intensity; and FP3, extruded using twin-screw extruder at high intensity.

Table 6. The apparent ileal and total tract digestibility of DM, OM, CP, and GE of the co-extruded 50:50 flaxseed-field pea (FP)

Item	Co-extruded flaxseed-field pea[1]				SEM	*P*-value[2]		
	FP0	FP1	FP2	FP3		FP0 vs. FP1, 2, and 3	FP1 vs. FP2 and 3	FP2 vs. FP3
Ileal digestibility, %								
DM	66.2	67.6	71.9	67.7	2.4	0.338	0.465	0.256
OM	68.1	70.4	73.5	69.4	2.2	0.266	0.692	0.219
CP	74.0	77.6	76.7	79.0	2.2	0.192	0.933	0.487
GE	67.0	71.0	71.5	71.0	2.3	0.156	0.921	0.901
DE, Mcal/kg DM	3.56	3.83	3.93	3.89	0.1	0.053	0.624	0.842
Total tract digestibility, %								
DM	75.0	80.5	77.5	76.0	1.9	0.202	0.141	0.602
OM	77.3	83.4	78.9	78.9	1.6	0.128	0.049	0.996
CP	79.2	77.3	76.1	81.9	1.9	0.722	0.484	0.064
GE	69.6	80.6	73.9	72.8	1.9	0.021	0.013	0.688
DE, Mcal/kg DM	3.70	4.35	4.06	3.99	0.10	0.006	0.031	0.621

[1]FP0, FP1, FP2, and FP3 was a 50:50 flaxseed-field pea mix processed as follows: FP0, ground and not extruded; FP1, extruded using single-screw extruder; FP2, extruded using twin-screw extruder at low intensity; and FP3, extruded using twin-screw extruder at high intensity.

Table 7. The apparent ileal AA digestibility of the experimental diets

Item	Diet[1]					SEM	*P*-value[2]			
	Basal	FP0	FP1	FP2	FP3		Basal vs. FP	FP0 vs. FP1, 2, and 3	FP1 vs. FP2 and 3	FP2 vs. FP3
Indispensable AA, %										
Arg	91.3	85.5	90.2	90.8	89.4	0.6	0.005	0.001	0.940	0.121
His	95.9	93.3	93.8	93.4	94.5	0.3	0.001	0.070	0.674	0.018
Ile	87.8	81.2	86.0	86.3	85.3	0.7	0.002	0.001	0.811	0.355
Leu	84.4	76.3	82.8	83.0	81.7	1.0	0.007	0.001	0.723	0.358
Lys	89.6	82.8	87.6	88.4	87.9	1.4	0.107	0.005	0.755	0.780
Phe	88.0	80.9	86.2	87.4	86.1	0.6	0.002	0.001	0.493	0.174
Thr	81.3	75.6	78.0	78.7	79.8	1.0	0.014	0.017	0.356	0.456
Val	78.1	67.0	75.8	76.2	76.2	1.1	0.011	0.001	0.803	0.969

[1]Diet FP0, FP1, FP2, and FP3, each contained 30% of a 50:50 flaxseed-field pea mix processed as follows: FP0, ground and not extruded; FP1, extruded using single-screw extruder; FP2, extruded using twin-screw extruder at low intensity; and FP3, extruded using twin-screw extruder at high intensity.

Table 8. The apparent ileal AA digestibility of the co-extruded 50:50 flaxseed-field pea (FP)

Item	Co-extruded flaxseed-field pea[1]				SEM	*P*-value[2]		
	FP0	FP1	FP2	FP3		FP0 vs. FP1, 2, and 3	FP1 vs. FP2 and 3	FP2 vs. FP3
Indispensable AA, %								
Arg	77.9	88.8	90.4	87.1	1.6	0.001	0.998	0.189
His	87.6	89.5	89.5	91.4	1.0	0.066	0.469	0.231
Ile	68.7	82.8	83.9	80.9	2.3	0.001	0.901	0.378
Leu	58.9	79.3	80.4	76.0	3.3	0.001	0.781	0.380
Lys	69.2	84.9	87.2	85.5	4.7	0.015	0.802	0.800
Phe	66.6	82.6	86.4	82.4	2.1	0.001	0.511	0.212
Thr	64.4	72.7	74.5	77.1	2.8	0.013	0.395	0.538
Val	52.4	71.8	73.3	72.8	3.1	0.001	0.756	0.912

[1]FP0, FP1, FP2, and FP3 was a 50:50 flaxseed-field pea mix processed as follows: FP0, ground and not extruded; FP1, extruded using single-screw extruder; FP2, extruded using twin-screw extruder at low intensity; and FP3, extruded using twin-screw extruder at high intensity.

Table 9. Analyzed fatty acid composition of the co-extruded 50:50 flaxseed-field pea (FP)

	Co-extruded flaxseed-field pea[1]			
Item	FP0	FP1	FP2	FP3
Fatty acids, % of total fatty acids				
C16:0 (palmitic)	6.04	6.10	6.20	5.87
C18:0 (stearic)	3.56	3.23	3.19	3.28
C20:0 (arachidic)	0.15	0.11	0.13	0.11
C18:1 n-9 (oleic)	19.36	18.38	18.27	18.49
C18:1 n-7 (vaccenic)	0.72	0.71	0.76	0.69
C18:2 (linoleic)	20.55	20.61	20.54	20.51
C18:3 (linolenic)	49.62	50.85	50.92	51.05
Fatty acids, % as-fed basis				
C16:0 (palmitic)	0.90	0.81	0.76	0.77
C18:0 (stearic)	0.53	0.43	0.39	0.43
C20:0 (arachidic)	0.02	0.01	0.02	0.01
C18:1 n-9 (oleic)	2.89	2.45	2.24	2.43
C18:1 n-7 (vaccenic)	0.11	0.10	0.09	0.09
C18:2 (linoleic)	3.07	2.75	2.52	2.69
C18:3 (linolenic)	7.41	6.79	6.24	6.70
Saturated fatty acids	1.46	1.26	1.17	1.22
Polyunsaturated fatty acids	13.48	12.09	11.09	11.91
Total fatty acids	14.96	13.38	12.29	13.15

[1]FP0, FP1, FP2, and FP3 was a 50:50 flaxseed-field pea mix processed as follows: FP0, ground and not extruded; FP1, extruded using single-screw extruder; FP2, extruded using twin-screw extruder at low intensity; and FP3, extruded using twin-screw extruder at high intensity.

Table 10. Fatty acids composition of the experimental diets

	Diets[1]				
Item	Basal	FP0	FP1	FP2	FP3
Fatty acid, % of total fatty acids					
C16:0 (palmitic)	13.53	8.19	7.68	7.50	8.06
C18:0 (stearic)	1.84	3.12	2.90	2.79	3.05
C20:0 (arachidic)	0.33	0.20	0.23	0.27	0.19
C18:1 n-9 (oleic)	29.27	22.50	26.05	27.74	23.03
C18:1 n-7 (vaccenic)	2.09	1.13	1.42	1.54	1.20
C18:2 (linoleic)	43.51	27.08	26.21	26.09	26.61
C18:3 (linolenic)	9.43	37.78	35.51	34.07	37.88
Fatty acid, % as-fed basis					
C16:0 (palmitic)	0.36	0.53	0.57	0.59	0.53
C18:0 (stearic)	0.05	0.20	0.21	0.22	0.20
C20:0 (arachidic)	0.01	0.01	0.02	0.02	0.01
C18:1 n-9 (oleic)	0.79	1.46	1.93	2.20	1.51
C18:1 n-7 (vaccenic)	0.06	0.07	0.11	0.12	0.08
C18:2 (linoleic)	1.17	1.76	1.94	2.07	1.74
C18:3 (linolenic)	0.25	2.45	2.63	2.70	2.48
Saturated fatty acids	0.42	0.75	0.80	0.84	0.74
Polyunsaturated fatty acids	2.27	5.74	6.61	7.09	5.81
Total fatty acids	2.69	6.49	7.42	7.94	6.56

[1]Diet FP0, FP1, FP2, and FP3, each contained 30% of a 50:50 flaxseed-field pea mix processed as follows: FP0, ground and not extruded; FP1, extruded using single-screw extruder; FP2, extruded using twin-screw extruder at low intensity; and FP3, extruded using twin-screw extruder at high intensity.

Table 11. The apparent ileal digestibility of fatty acids, and apparent ileal and total tract digestibility of ether extract in the experimental diets

Item	Diets[1]					SEM	*P*-value[2]			
	Basal	FP0	FP1	FP2	FP3		Basal vs. FP	FP0 vs. FP1, 2, and 3	FP1 vs. FP2 and 3	FP2 vs. FP3
Ileal digestibility, %										
C16:0 (palmitic)	84.1	72.5	82.4	77.8	74.2	1.3	< 0.001	0.002	0.001	0.067
C18:0 (stearic)	76.4	63.9	80.7	73.1	65.8	2.3	0.055	0.005	0.002	0.048
C20:0 (arachidic)	74.7	51.5	66.7	67.6	47.5	3.0	< 0.001	0.021	0.028	< 0.001
C18:1 n-9 (oleic)	90.0	74.1	87.1	82.4	75.6	1.5	< 0.001	< 0.001	< 0.001	0.007
C18:1 n-7 (vaccenic)	89.3	77.1	86.0	83.8	79.1	1.5	< 0.001	0.004	0.024	0.041
C18:2 (linoleic)	91.1	80.9	88.4	86.0	82.6	2.3	0.024	0.095	0.166	0.313
C18:3 (linolenic)	92.3	75.4	90.5	83.8	78.6	3.2	0.015	0.034	0.036	0.278
Saturated fatty acids	83.0	69.8	81.6	76.3	71.5	1.5	< 0.001	0.002	0.001	0.041
Unsaturated fatty acids	90.8	76.8	88.8	84.0	79.0	2.4	0.007	0.023	0.028	0.165
Total fatty acids	88.7	75.5	87.6	82.7	77.7	2.2	0.008	0.016	0.019	0.135
Ether extract	92.2	85.2	91.2	88.6	87.5	1.9	0.071	0.099	0.192	0.685
Total tract digestibility, %										
Ether extract	87.0	79.3	91.0	86.5	84.3	1.2	0.218	< 0.001	0.003	0.210

[1]Diet FP0, FP1, FP2, and FP3, each contained 30% of a 50:50 flaxseed-field pea mix processed as follows: FP0, ground and not extruded; FP1, extruded using single-screw extruder; FP2, extruded using twin-screw extruder at low intensity; and FP3, extruded using twin-screw extruder at high intensity.

Table 12. The apparent ileal digestibility of fatty acids, and apparent ileal and total tract digestibility of ether extract in the co-extruded 50:50 flaxseed-field pea (FP)

Fatty acid	Co-extruded flaxseed-field pea[1]				SEM	*P*-value[2]		
	FP0	FP1	FP2	FP3		FP0 vs. FP1, 2, and 3	FP1 vs. FP2 and 3	FP2 vs. FP3
Ileal digestibility, %								
C16:0 (palmitic)	61.8	81.0	73.1	65.0	2.6	0.006	0.005	0.059
C18:0 (stearic)	61.3	81.6	72.5	63.6	2.6	0.006	0.003	0.043
C20:0 (arachidic)	36.4	62.3	64.7	49.2	7.9	0.098	0.611	0.412
C18:1 n-9 (oleic)	64.5	85.9	79.8	67.3	2.6	0.001	0.460	0.669
C18:1 n-7 (vaccenic)	62.9	84.1	81.2	68.8	3.2	0.003	0.047	0.024
C18:2 (linoleic)	72.0	86.5	82.6	75.1	5.0	0.138	0.246	0.311
C18:3 (linolenic)	74.1	90.3	83.2	77.5	4.1	0.074	0.079	0.353
Saturated fatty acids	61.1	80.8	72.6	63.9	2.6	0.006	0.005	0.046
Unsaturated fatty acids	71.4	88.2	82.0	74.6	3.8	0.051	0.069	0.208
Total fatty acids	70.1	87.2	80.9	73.2	3.6	0.039	0.052	0.177
Ether extract	82.4	90.7	86.2	85.7	2.9	0.162	0.212	0.891
Total tract digestibility, %								
Ether extract	76.3	92.9	86.2	83.2	1.6	< 0.001	0.003	0.221

[1]FP0, FP1, FP2, and FP3 was a 50:50 flaxseed-field pea mix processed as follows: FP0, ground and not extruded; FP1, extruded using single-screw extruder; FP2, extruded using twin-screw extruder at low intensity; and FP3, extruded using twin-screw extruder at high intensity.

Feeding co-extruded flaxseed to pigs: Effects of duration and feeding level on growth performance and backfat fatty acid composition of grower-finisher pigs

M. Juárez[1], M. E. R. Dugan[1,*], N. Aldai[1], J. L. Aalhus[1], J. F. Patience[2], R. T. Zijlstra[3], A. D. Beaulieu[2]

[1]Agriculture and Agri-Food Canada, Lacombe Research Centre, 6000 C & E Trail, Lacombe, Alberta, Canada. T4L 1W1.

[2]Prairie Swine Centre, Inc., Saskatoon, SK, Canada. S7H 5N9.

[3]University of Alberta, Edmonton, AB, Canada. T6G 2P5.

[*]Corresponding author: Mike E. R. Dugan, Agriculture and Agri-Food Canada, Lacombe Research Centre, 6000 C & E Trail, Lacombe, Alberta, Canada T4L 1W1

E-mail: Mike.Dugan@AGR.GC.CA

Abstract

To examine the effect of co-extrusion on subsequent n-3 fatty acids in pig tissues, 8 pigs (barrows and gilts) were assigned to either a control treatment or one of nine treatments arranged in a 3x3 factorial design with 3 levels of co-extruded flaxseed (5, 10 and 15%) and 3 durations of feeding (4, 8 and 12 weeks). Feed conversion improved slightly (P=0.01) with increasing dietary flaxseed but feeding flax for more than 8 weeks reduced average daily gain (P=0.02). In general, the duration and level of co-extruded flaxseed feeding affected (P<0.05) most fatty acids except for 22:6n-3 (P>0.05). Increasing the duration of flax feeding led to significant quadratic effects in backfat 18:3n-3 (P<0.001) and total n-3 fatty acids (P=0.002) when feeding 5% co-extruded flaxseed. Those increases were linear (P<0.001) when feeding 10 and 15% co-extruded flaxseed. Consequently feeding higher levels of flax for shorter periods versus lower levels for longer periods appears to be more efficient at increasing n-3 fatty acids in pig backfat, but increases appeared to be less consistent. Moreover the addition of a 50:50 mix of extruded flax/peas to pig diets provided a highly available source of 18:3n-3 yielding n-3 fatty acid enrichments in backfat comparable to studies where extracted flaxseed oil was fed. Feeding flax co-extruded with field peas can be used to optimize consistent enrichments of n-3 fatty acids in back fat and relatively small amounts of this fat could be used to manufacture pork products to meet Canadian standards for n-3 fatty acid enrichment.

Keywords: omega-3; flax; regression; linseed; pork

Introduction

Historically humans consumed diets with an n-6 to n-3 fatty acid ratio of 1:1. In Western diets, this ratio has increased over the last 100 years to an average of 15:1 (Simopoulos, 2008). Consuming n-3 fatty acids may provide health benefits by reducing the risks for several diseases including heart disease (Ruxton, Reed, Simpson & Millington, 2004), cancer (Larsson, Kumlin, Ingelman-Sundberg & Wolk, 2004) and inflammatory diseases (Calder & Grimble, 2002). Thus the potential use of livestock products as vehicles to deliver n-3 fatty acids has been the subject of intensive research (Moghadasian, 2008). In this context, dietary strategies used to customise fatty acid composition of pig fat have been proven to be very effective because dietary fatty acids can be incorporated into pig fat with little modification (Bee, Jacot, Guex & Biolley, 2008; D'Arrigo et al., 2002; Wood et al., 2008). However, differences in the relationships between intake and deposition exist, and these relate to whether the specific fatty acid can be synthesized *in vivo*. A strong relationship is seen for essential fatty acids [linoleic (18:2n-6) and α-linolenic (18:3n-3) acids] and their n-3 and n-6 elongation and desaturation products. On the other hand, saturated and monounsaturated fatty acids are synthesised *in vivo* and their deposition is less influenced by diet (Enser, Richardson, Wood, Gill & Sheard, 2000).

Flax is the richest oilseed source of 18:3n-3 and feeding flax to pigs has been used to increase levels of n-3 fatty acids in pork, as reviewed by Nguyen, Nuijens, Everts, Salden and Beynen (2003). Recently Thacker, Racz and Soita (2004) reported feeding flax co-extruded with field pea could avoid problems with grinding and storage, and Htoo, Meng, Patience, Dugan and Zijlstra (2008) investigated extrusion techniques for a flax/pea mixture to optimize 18:3n-3 availability. Htoo et al. (2008) fed pigs a 50:50 mixture of flax and peas that was either ground through a knife mill with a 2 mm sieve or co-extruded using single or double screw techniques. Single screw extrusion with minimal water input increased 18:3n-3 availability in the flax/pea mix by 16 % relative to ground flax/peas and by 10 % relative to other extrusion techniques. In contrast, Thacker et al. (2004) found feeding 12 % flax as a 50:50 mix of flax/peas reduced rates of body weight gain in finisher pigs whereas most other studies have found pigs can be fed up to 15 % flax without affecting performance (ex. Romans, Johnson, Wulf, Libal & Costello, 1995a; Romans, Wulf, Johnson, Libal & Costello, 1995b). However regional variations in oil content and fatty acid distribution in flaxseed (Hall Iii, Tulbek & Xu, 2006) makes comparison of results from different areas difficult. Moreover incorporation rates of 18:3n-3 when feeding flax have been quite variable and this can partly be attributed to processing challenges due to its high oil and 18:3n-3 content, but little attention has been paid to optimizing 18:3n-3 availability.

The objectives of the present research were, therefore, to feed single screw extruded flax/peas (50:50) to grow/finish pigs for different durations and levels and examine the effects on animal performance and n-3 fatty acid incorporation into backfat. The dietary inclusion and the duration of flax feeding were similar to those fed by Thacker et al. (2004) to determine if and when single screw extruded flax would negatively influence animal performance. In addition, a 3 x 3 factorial design was employed to determine if 18:3n-3 and n-3 fatty acids levels in backfat would plateau (Fontanillas, Barroeta, Baucells & Guardiola, 1998; Matthews, Homer, Thies & Calder, 2000) or remain linear (Cherian & Sim, 1995; Riley, Enser, Nute & Wood, 2000; Romans et al., 1995a; Romans et al., 1995b) when feeding to a slaughter end point typical for Canada (i.e. 115 kg).

Material and methods

Animal management

Animals involved in this study were cared for according to the guidelines set out by the Canadian Council of Animal Care (CCAC, 1993) under a protocol approved by the University of Saskatchewan Committee on Animal Care and Supply. The study included 80 pigs with an initial body weight of 31 ± 3 kg (mean ± SD). Animals were stratified by weight, parentage and gender

and included 4 gilts and 4 barrows per treatment. Pigs were housed individually in 0.91 x 1.83 m (1.67 m^2) pens with fully slatted floors and each pen was equipped with a single space feeder and nipple drinker.

The study included a control treatment (fed for 12 weeks) and nine treatments arranged in a 3 x 3 factorial design with 3 levels of extruded flaxseed (5, 10 and 15 %) and 3 durations of feeding (4, 8 and 12 weeks). Pigs on the 4 and 8 week treatments received control diets for 8 or 4 weeks, respectively prior to receiving their treatment diets.

Pigs had *ad libitum* access to feed and water. Pig weights and feed consumption were measured every two weeks and used to calculate average daily gain (ADG), average daily feed intake (ADFI) and feed conversion. Diets were formulated and adjusted every 4 weeks (0 to 4, 4 to 8 and 8 to 12 weeks; Tables 1, 2, 3) to meet the nutrient requirement of the pigs over the experiment (NRC, 1998). Diets were based on wheat, barley and soybean meal. Field peas were added to diets at a constant level within each feeding period taking into consideration the field pea included in co-extruded product, and tallow was used to balance energy levels among diets within phase. Diets within each feeding period had equal apparent ileal digestible lysine per Mcal of digestible energy (DE). Experimental diets included LinPro®, a commercial product (O&T Farms, Regina, Saskatchewan, Canada) containing a 50:50 mixture of co-extruded flaxseed and field peas using single screw extrusion at 400 psi without water and a barrel temperature of 135°C (Htoo et al., 2008).

Adipose tissue collection

One day prior to slaughter, subcutaneous fat from each pig was collected using an 8 mm biopsy punch (Acuderm Inc., USA) at the 10th rib, approximately 5 cm from the backbone. The biopsy site was scrubbed and cleaned with isopropyl alcohol and iodine solution before injecting local anaesthesia [2 cc of 2 % Lidocaine, (Gatlin, See, Hansen, Sutton & Odle, 2002)]. An incision (~3 to 4 cm) was made at the biopsy site before applying the biopsy punch in order to minimize the quantity of intact skin with the fat samples. The subcutaneous fat samples were stored in a freezer at –80°C until analyzed.

Chemical analyses

Feed fatty acid methyl esters (FAME) were prepared according to Sukhija and Palmquist (1988) and backfat (inner layer) FAME were prepared using the procedure described by Dugan, Kramer, Robertson, Meadus, Aldai and Rolland (2007). Feed and backfat FAME were analysed according to Dugan et al. (2007).

Statistical Analysis

The data were analyzed using the MIXED procedure within SAS (SAS, 2001). Individual pigs were the experimental unit. The statistical design used in the present experiment was an augmented factorial [i.e. 3 levels of flaxseed x 3 durations of flaxseed feeding x 2 genders and a single control group (i.e. 4 gilts and 4 barrows) fed the control diet for 12 weeks]. The statistical model included flaxseed level, length of feeding, gender and the interactions. Initial statistical analysis examined the main effects of flaxseed inclusion, length of feeding and the interactions. As such main effects could not be computed when the control was included in the model, therefore, initially control data were not used and the model included gender, diet, weeks of feeding and all their interactions. To further explore the effects of feeding flax at different levels for different durations on backfat fatty acid composition, linear and quadratic contrasts were conducted and this included data from control animals.

Results and discussion

Growth Performance

There were no two or three-way interactions for ADG, ADFI or feed conversion ($P > 0.05$). As expected, barrows had higher ADG (7.8 %), ADFI (14.3 %) and lower feed conversion (7.9 %) than gilts ($P < 0.01$; Table 5). With increasing dietary flaxseed, ADFI decreased from 2.62 to 2.45 kg/d ($P = 0.01$, Table 5) but ADG was unaffected ($P = 0.40$) and thus feed conversion improved slightly (from 0.38 to 0.39; $P = 0.01$). The lack of, or slight positive effects of adding flax to the diets on animal performance is in agreement with the majority of studies (Corino, Musella & Mourot, 2008; Fontanillas et al., 1998; Kouba, Enser, Whittington, Nute & Wood, 2003; Matthews et al., 2000; Riley et al., 2000; Romans et al., 1995a; Romans et al., 1995b; Wiseman, Redshaw, Jagger, Nute & Wood, 2000). This is in contrast with Thacker et al. (2004) who found that pigs could tolerate up to 15 % dietary flax in the grower period but 12 % flax in the finishing diet reduced ADG. In the present experiment, increasing levels of co-extruded flaxseed, tended to reduce ADFI ($P = 0.06$; Table 5), but did not affect ADG. Prolonged feeding of co-extruded flaxseed, independent of its level of dietary inclusion, reduced ADG ($P = 0.01$). This observation together with the results of Thacker et al. (2004) would then suggest that long-term feeding of co-extruded flaxseed may marginally reduce ADG, but short-term feeding does not, even at high inclusion levels.

Backfat fatty acid composition

Diet by gender, feeding duration (weeks) by gender or diet by feeding duration by gender interactions were not found for backfat fatty acid composition ($P > 0.05$). Gender influenced backfat fatty acid composition with gilts having less ($P = 0.04$) saturated fatty acids (SFA) and more ($P = 0.03$) n-6 fatty acids (Table 6). Similar results were reported by (Nuernberg et al., 2005) and likely relate to barrows being fatter with larger adipocytes. This would result in a greater neutral lipid to phospholipid ratio in barrow backfat with neutral lipids being relatively rich in SFA and phospholipids relatively rich in n-6 fatty acids (Riley et al., 2000). All differences between genders were, however, less than 1 % of total fatty acids and would be of limited practical significance.

Significant main effects ($P < 0.05$) for diet (% flax) and feeding duration (week) were found, in addition to diet by week interactions for most individual fatty acids except for 22:6n-3 ($P > 0.05$; Table 7). Several authors have reported a lack of effect of flax diets on tissue levels of 22:6n-3 (Ahn, Lutz & Sim, 1996; Cherian et al., 1995; Fontanillas et al., 1998; Haak, De Smet, Fremaut, Van Walleghem & Raes, 2008; Raes, De Smet & Demeyer, 2004; Riley et al., 2000), and only a few studies have reported increased levels of 22:6n-3 after feeding a relatively low level (~2-2.5 %) of dietary flax (Corino et al., 2008; Enser et al., 2000). Long chain fatty acid metabolism is controlled by a complex enzymatic system, consisting of desaturases and elongases (Raes et al., 2004). These enzymes act both on the n-6 and n-3 fatty acids but have a preference for the n-3 (Brenner, 1989). The lack of effect on 22:6n-3 fatty acid may be explained by competition for $\Delta 6$ desaturase activity between 18:3n-3 and the precursor for 22:6n-3 (i.e. 24:5n-3), when the dietary concentration of 18:3n-3 is high (Cameron, Wood, Enser, Whittington, Penman & Robinson, 2000).

Diet, feeding duration and diet by feeding duration effects ($P < 0.05$) were found for total polyunsaturated fatty acids (PUFA), monounsaturated fatty acids (MUFA), SFA, n-3 and n-6 fatty acids and the n-6/n-3 ratio (Table 7). In general, feeding flax containing diets for increasing durations prior to slaughter led to linear ($P < 0.05$) increases in 18:2n-6, 20:3n-3, 20:5n-3, 22:5n-3, total PUFA and n-6 fatty acids and reductions in 20:4n-6 and total MUFA (Table 8). The linear increase ($P < 0.001$) for 20:2n-6 and the linear decrease ($P < 0.001$) in SFA were only observed when 10 and 15 % flax was included in the diet. The n-6/n-3 ratio decreased quadratically ($P < 0.001$), while the quadratic relationship for total n-3 content was stronger when feeding 5 % ($P =$

0.002) than when feeding 10 (P = 0.192) or 15 % ($P = 0.041$) co-extruded flaxseed containing diets. The quadratic relationship for n-3 fatty acids when feeding 5 % flax in the diets was also observed for 18:3n-3 ($P < 0.001$), while increases in other 18:3n-3 elongation and desaturation products (20:3n-3, 20:5n-3 and 22:5n-3) were found to be linear.

The effect of feeding flaxseed on tissue deposition of n-3 fatty acids in pigs has been found to be quite variable (Nguyen et al., 2003). Feeding extracted flaxseed oil likely provides the most digestible form of 18:3n-3, but would be relatively expensive for inclusion in swine diets. D'Arrigo et al. (2002) fed 3 % flaxseed oil (equivalent to 7.5 % flaxseed containing 40 % oil) to gilts for 8 weeks from 48 to 100 kg and found 9.29 % n-3 fatty acids in backfat fatty acids. Results from the present experiment indicate co-extruded flax/pea mixture had a comparably high n-3 fatty acid availability yielding 6.2 and 11.7 % (average 8.9 %) n-3 fatty acids when feeding 5 and 10 % flaxseed for 8 weeks. Fontanillas, Barroeta, Baucells and Codony (1997) fed 4 % flaxseed oil, equivalent to ~10 % flaxseed to barrows for ~12 weeks and found 13.5 % n-3 fatty acids in backfat and present results were equally as impressive yielding 15.8 % n-3 fatty acids in backfat when feeding 10 % flax for 12 weeks. Present findings of 9.79, 16.1 and 21.6 % n-3 fatty acids in backfat when feeding 15 % co-extruded flaxseed for 4, 8 and 12 weeks respectively appear higher than those reported by several authors. Romans et al. (1995b) found 6.92 % n-3 fatty acids in inner backfat when feeding 15 % flax to pigs for 4 weeks, while Thacker et al. (2004) found 13.5 % n-3 fatty acids in backfat when feeding 15 % flax for close to 14 weeks, and Specht-Overholt et al. (1997) found 12 % n-3 fatty acids in backfat when feeding 15 % flax to finisher pigs for 7 weeks. Finally, Huang, Zhan, Luo, Liu and Peng (2008) found 9.72 % n-3 fatty acids in backfat fatty acids when feeding 10 % flax to pigs for close to 13 weeks. Hence co-extruding flax with peas can, therefore, be used to optimize n-3 fatty acid availability from flax and optimization of flaxseed processing will no doubt have an important influence on the profitability and viability of producing n-3 enhanced pork.

In Canada, 300 mg n-3 fatty acids per serving (100 g) is required for an enrichment claim (CFIA & Health-Canada, 2009). Thus, when co-extruded flax/pea mixture was used as a source of dietary 18:3n-3: 3.5 g of backfat from pigs fed 10 or 15 % flax for 8 or 4 weeks, respectively, 2.5 g of backfat from pigs fed 10 or 15 % flax for 12 or 8 weeks, respectively, or 2.0 g of backfat from pigs fed 15 % flax for 12 weeks would achieve the n-3 fatty acid levels required for an enrichment claim (assuming 85% fat in backfat). Additionally, besides the potential manufacturing of pork products enriched in n-3 fatty acids using backfat, commercial lean meat from pigs fed flax co-extruded with field peas could likely achieve the required n-3 levels by including the amount of fat (subcutaneous, intermuscular and intramuscular) usually present in retail cuts.

Adding flax to pig diets, does not however only affect backfat levels of n-3 fatty acids. Although there was a decrease in the relative content of 18:2n-6 in dietary fat when flax was added to the diet, the increased level of fat in flax containing diets actually led to increased absolute amounts (mg/g) of 18:2n-6 in the diet as the level of flax increased. Consequently this led to linear increases in backfat 18:2n-6 and total n-6 fatty acids when flax containing diets were fed for increasing durations. A linear increase in 20:2n-6 was, however, only found when the 10 and 15 % flax diets were fed for increasing durations, and backfat levels of 20:4n-6 were linearly reduced when flax containing diets were fed for increasing durations. The decrease in 20:4n-6 levels may be due to the competition between 18:2n-6 and 18:3n-3 for desaturation and elongation to form 20:4n-6 and 20:5n-3 (Cherian et al., 1995). The decrease in 20:4n-6 levels might be considered as beneficial, since increasing concentrations of this fatty acid in membrane phospholipids result in an overproduction of eicosanoids and induce platelet aggregation

(Kristensen, Schmidt & Dyerberg, 1989), which may contribute to hardening of the arteries and other chronic conditions (Simopoulos, 2002).

The overall changes in backfat levels of n-3 and n-6 when feeding the co-extruded flaxseed containing diets for increasing durations prior to slaughter were well reflected by significant linear ($P < 0.001$) increases in total PUFA. Increases in PUFA, however, meant either concomitant reductions in SFA and or MUFA. Remarkably, the level of SFA only showed a linear decline ($P < 0.001$) when feeding the 10 and 15 % co-extruded flax diets for increasing durations. On the other hand, increases in PUFA when feeding flax containing diets for increasing duration were inversely mirrored by linear reductions in MUFA ($P < 0.001$), probably due to inhibition of Δ9 desaturase activity as the level of n-3 fatty acids increased in the diet (Waters, Kelly, O'Boyle, Moloney & Kenny, 2009).

N-3 fatty acid enrichment paradox

Understanding the evolution of n-3 fatty acid enrichment in backfat is an important concept when trying to attain a certain level of enrichment for a particular weight of pig. When following the enrichment of n-3 fatty acids in backfat over time in pigs fed flax from 26 to 95 kg, Fontanillas et al. (1998) found a rapid enrichment leading to a plateau after about 4 weeks and similar observations were noted by D'Arrigo et al. (2002). Based on these data, the assumption might be made that to enrich n-3 fatty acids in market weight pigs, feeding pigs during the last 4 weeks of the finishing period would be enough to reach the maximum level of enrichment. The rate of enrichment and duration till plateau are however influenced by the level of flax supplementation and the starting weight of the pigs. The rate of fat deposition is higher in heavier pigs, which also have more body fat diluting n-3 fatty acids originating from dietary flax. On the other hand, feeding higher levels of flax may provide 18:3n-3 in excess of its metabolism/catabolism processes, resulting in higher rates of n-3 fatty acid deposition. Thus, in the present study, when feeding 5 % flax co-extruded with field peas a plateau in total n-3 fatty acids was observed for periods longer than 8 weeks, with no significant increase when the feeding duration was increased from 8 to 12 weeks (Table 7; Figure 1). However, when feeding 10 and 15 % flax the level of n-3 fatty acids did not plateau and continued to increase ($P < 0.01$) between 8 and 12 weeks. In addition, the quadratic component (Table 8) was stronger for the lowest level than for the higher levels of flax addition, which had clear linear relationships, indicating a lower dilution effect with increasing dietary flax. Similar results have been reported by Huang et al. (2008) when feeding 10 % flaxseed for different periods prior to slaughter. N-3 fatty acid levels can, therefore, be rapidly enriched in young pigs but paradoxically to achieve high levels of n-3 fatty acids in market weight pigs, relatively long feeding periods are still required. To yield the same level of n-3 fatty acid enrichment in backfat, however, shorter feeding periods with higher levels of dietary flax appear to be more efficient than longer feeding periods with lower levels of dietary flax. To produce n-3 enriched pork products, however, both the level and consistency of enrichment are important. Consistency from feeding lower flax levels for longer durations was observed to be higher than for high levels for shorter durations. As shown in figure 1, feeding 5 % co-extruded flax for 12 weeks resulted in a lower standard error than feeding 10 % for 8 weeks or 15 % for 4 weeks (0.26 *vs* 0.40 *vs* 0.64). When feeding 5 % flax for 8 weeks, the standard error value was lower than feeding 10 % flax for 4 weeks (0.25 *vs* 0.30), even if both diets resulted in a similar total n-3 fatty acid content (Table 7). A similar effect was observed when the variability from 10 % - 12 weeks and 15 % - 8 weeks diets were compared (0.38 vs 1.18). Hence to more consistently yield the same level of n-3 fatty acid enrichment in backfat, shorter feeding periods with higher levels of dietary co-extruded flax appear to be more efficacious than longer feeding periods with lower levels of dietary flax. In practical terms, to be able to produce pork with consistently high levels of n-3 fatty acids, one will therefore likely need to strike a balance between feeding high

levels of flax for short durations, which provides efficient n-3 fatty acid deposition, and feeding lower levels of flax for longer durations, which provides more consistent rates of deposition.

Conclusions

Feeding up to 15 % flax for 8 weeks had no impact on live animal performance. Feeding any level of flax for 12 weeks reduced average daily gain but feeding higher levels of flax improved feed efficiency. The addition of a 50:50 mix of extruded flax/peas to pig diets provided a highly available source of 18:3n-3 yielding n-3 fatty acid enrichments in backfat comparable to reports when feeding supplemental flax seed oil. Enrichments of n-3 fatty acids, according to Canadian standards, can be obtained in pork products when relatively low levels of backfat from pigs fed flaxseed are included. Increasing the duration of flax supplementation resulted in a plateau in backfat total n-3 fatty acids when feeding 5 % flax for 8 weeks but plateaus were not evident when feeding either 10 or 15 % flax for 12 weeks. Hence feeding higher levels of co-extruded flaxseed for shorter periods versus lower levels for longer periods appears to be more efficient at increasing n-3 fatty acids in pig backfat but more consistent enrichments were apparent when feeding lower levels of flaxseed for longer durations.

Acknowledgements

Financial support was provided by Saskatchewan Agriculture Development Fund and Flax Canada 2015. Dr. N. Aldai gratefully acknowledges the receipt of a research contract from the 7th European Community Program (Marie Curie International Outgoing Fellowship). And Dr. M. Juárez acknowledges the receipt of a NSERC fellowship funded through the AAFC ABIP-FOBI program.

References

Ahn, D. U., Lutz, S., & Sim, J. S. (1996). Effects of dietary [alpha]-linolenic acid on the fatty acid composition, storage stability and sensory characteristics of pork loin. *Meat Science*, *43*(3-4), 291-299.

Bee, G., Jacot, S., Guex, G., & Biolley, C. (2008). Effects of two supplementation levels of linseed combined with CLA or tallow on meat quality traits and fatty acid profile of adipose and different muscle tissues in slaughter pigs. *Animal*, *2*(5), 800-811.

Brenner, R. R. (1989). Factors influencing fatty acid chain elongation and desaturation. *In The Role of fats in human nutrition. Edited by A.J. Vergroesen and M. Crawford, 2nd ed. New York : Academic Press*, 45-79.

Calder, P. C., & Grimble, R. F. (2002). Polyunsaturated fatty acids, inflammation and immunity. *European Journal of Clinical Nutrition*, *56*(Suppl. 3), S14-S19.

Cameron, N. D., Wood, J. D., Enser, M., Whittington, F. M., Penman, J. C., & Robinson, A. M. (2000). Sensitivity of pig genotypes to short-term manipulation of plasma fatty acids by feeding linseed. *Meat Science*, *56*(4), 379-386.

CCAC (1993). Canadian Council on Animal Care. In E. B. Olfert, B. M. Cross, & A. A. McWilliam (Eds.). *A guide to the care and use of experimental animals. Vol. 1, (2nd ed.). Ottawa, ON: CCAC.*

CFIA, & Health-Canada (2009). Guide to Food Labelling and Advertising. *Canadian Food Inspection Agency*, http://www.inspection.gc.ca/english/fssa/labeti/guide/toce.shtml.

Cherian, G., & Sim, J. S. (1995). Dietary a-Linolenic acid alters the fatty acid composition of lipid classes in swine tissues. *Journal of Agricultural and Food Chemistry*, *43*(11), 2911-2916.

Corino, C., Musella, M., & Mourot, J. (2008). Influence of extruded linseed on growth, carcass composition, and meat quality of slaughtered pigs at one hundred ten and one hundred sixty kilograms of liveweight. *Journal of Animal Science*, *86*(8), 1850-1860.

D'Arrigo, M., Hoz, L., Lopez-Bote, C. J., Cambero, I., Pin, C., Rey, A. I., & Ordóñez, J. A. (2002). Effect of dietary linseed oil and α-tocopherol on selected properties of pig fat. *Canadian Journal of Animal Science*, *82*(3), 339-346.

Dugan, M. E. R., Kramer, J. K. G., Robertson, W. M., Meadus, W. J., Aldai, N., & Rolland, D. C. (2007). Comparing subcutaneous adipose tissue in beef and muskox with emphasis on trans 18:1 and conjugated linoleic acids. *Lipids*, *42*(6), 509-518.

Enser, M., Richardson, R. I., Wood, J. D., Gill, B. P., & Sheard, P. R. (2000). Feeding linseed to increase the n-3 PUFA of pork: Fatty acid composition of muscle, adipose tissue, liver and sausages. *Meat Science*, *55*(2), 201-212.

Fontanillas, R., Barroeta, A., Baucells, M. D., & Codony, R. (1997). Effect of Feeding Highly Cis-Monounsaturated, Trans, or n-3 Fats on Lipid Composition of Muscle and Adipose Tissue of Pigs. *Journal of Agricultural and Food Chemistry*, *45*(8), 3070-3075.

Fontanillas, R., Barroeta, A., Baucells, M. D., & Guardiola, F. (1998). Backfat Fatty Acid Evolution in Swine Fed Diets High in Either cis-Monounsaturated, trans, or (n-3) Fats. *Journal of Animal Science*, *76*(4), 1045-1055.

Gatlin, L. A., See, M. T., Hansen, J. A., Sutton, D., & Odle, J. (2002). The effects of dietary fat sources, levels, and feeding intervals on pork fatty acid composition. *Journal of Animal Science*, *80*(6), 1606-1615.

Haak, L., De Smet, S., Fremaut, D., Van Walleghem, K., & Raes, K. (2008). Fatty acid profile and oxidative stability of pork as influenced by duration and time of dietary linseed or fish oil supplementation. *Journal of Animal Science*, *86*(6), 1418-1425.

Hall Iii, C., Tulbek, M. C., & Xu, Y. (2006). Flaxseed. *Advances in Food and Nutrition Research*, vol. 51 (pp. 1-97).

Htoo, J. K., Meng, X., Patience, J. F., Dugan, M. E. R., & Zijlstra, R. T. (2008). Effects of coextrusion of flaxseed and field pea on the digestibility of energy, ether extract, fatty acids, protein, and amino acids in grower-finisher pigs. *Journal of Animal Science*, *86*(11), 2942-2951.

Huang, F. R., Zhan, Z. P., Luo, J., Liu, Z. X., & Peng, J. (2008). Duration of dietary linseed feeding affects the intramuscular fat, muscle mass and fatty acid composition in pig muscle. *Livestock Science*, *118*(1-2), 132-139.

Kouba, M., Enser, M., Whittington, F. M., Nute, G. R., & Wood, J. D. (2003). Effect of a high-linolenic acid diet on lipogenic enzyme activities, fatty acid composition, and meat quality in the growing pig. *Journal of Animal Science*, *81*(8), 1967-1979.

Kristensen, S. D., Schmidt, E. B., & Dyerberg, J. (1989). Dietary supplementation with n-3 polyunsaturated fatty acids and human platelet function: a review with particular emphasis on implications for cardiovascular disease. *Journal of Internal Medicine, Supplement*, *225*(731), 141-150.

Larsson, S. C., Kumlin, M., Ingelman-Sundberg, M., & Wolk, A. (2004). Dietary long-chain n-3 fatty acids for the prevention of cancer: A review of potential mechanisms. *American Journal of Clinical Nutrition*, *79*(6), 935-945.

Matthews, K. R., Homer, D. B., Thies, F., & Calder, P. C. (2000). Effect of whole linseed (*Linum usitatissimum*) in the diet of finishing pigs on growth performance and on the quality and fatty acid composition of various tissues. *British Journal of Nutrition*, *83*(6), 637-643.

Moghadasian, M. H. (2008). Advances in dietary enrichment with N-3 fatty acids. *Critical Reviews in Food Science and Nutrition*, *48*(5), 402-410.

Nguyen, L. Q., Nuijens, M. C. G. A., Everts, H., Salden, N., & Beynen, A. C. (2003). Mathematical relationships between the intake of n-6 and n-3 polyunsaturated fatty acids and their contents in adipose tissue of growing pigs. *Meat Science*, *65*(4), 1399-1406.

NRC (1998). Nutrient Requirements of Swine. *National academic press, Subcommittee on Swine Nutrition, Committee on Animal Nutrition, National Research Council, 10th Revised Edition.*

Nuernberg, K., Fischer, K., Nuernberg, G., Kuechenmeister, U., Klosowska, D., Eliminowska-Wenda, G., Fiedler, I., & Ender, K. (2005). Effects of dietary olive and linseed oil on lipid composition, meat quality, sensory characteristics and muscle structure in pigs. *Meat Science*, *70*(1), 63-74.

Raes, K., De Smet, S., & Demeyer, D. (2004). Effect of dietary fatty acids on incorporation of long chain polyunsaturated fatty acids and conjugated linoleic acid in lamb, beef and pork meat: A review. *Animal Feed Science and Technology*, *113*(1-4), 199-221.

Riley, P. A., Enser, M., Nute, G. R., & Wood, J. D. (2000). Effects of dietary linseed on nutritional value and other quality aspects of pig muscle and adipose tissue. *Animal Science*, *71*(3), 483-500.

Romans, J. R., Johnson, R. C., Wulf, D. M., Libal, G. W., & Costello, W. J. (1995a). Effects of ground flaxseed in swine diets on pig performance and on physical and sensory characteristics and omega-3 fatty acid content of pork: I. Dietary level of flaxseed. *Journal of Animal Science*, *73*(7), 1982-1986.

Romans, J. R., Wulf, D. M., Johnson, R. C., Libal, G. W., & Costello, W. J. (1995b). Effects of ground flaxseed in swine diets on pig performance and on physical and sensory characteristics and omega-3 fatty acid content of pork: II. Duration of 15% dietary flaxseed. *Journal of Animal Science*, *73*(7), 1987-1999.

Ruxton, C. H. S., Reed, S. C., Simpson, M. J. A., & Millington, K. J. (2004). The health benefits of omega-3 polyunsaturated fatty acids: A review of the evidence. *Journal of Human Nutrition and Dietetics*, *17*(5), 449-459.

Simopoulos, A. P. (2002). Omega-3 fatty acids and cardiovascular disease: The epidemiological evidence. *Environmental Health and Preventive Medicine*, *6*(4), 203-209.

Simopoulos, A. P. (2008). The importance of the omega-6/omega-3 fatty acid ratio in cardiovascular disease and other chronic diseases. *Experimental biology and medicine (Maywood, N.J.)*, *233*(6), 674-688.

Specht-Overholt, S., Romans, J. R., Marchello, M. J., Izard, R. S., Crews, M. G., Simon, D. M., Costello, W. J., & Evenson, P. D. (1997). Fatty Acid Composition of Commercially Manufactured Omega-3 Enriched Pork Products, Haddock, and Mackerel. *Journal of Animal Science*, *75*(9), 2335-2343.

Sukhija, P. S., & Palmquist, D. L. (1988). Rapid method for determination of total fatty acid content and composition of feedstuffs and feces. *Journal of Agricultural and Food Chemistry*, *36*(6), 1202-1206.

Thacker, P. A., Racz, V. J., & Soita, H. W. (2004). Performance and carcass characteristics of growing-finishing pigs fed barley-based diets supplemented with Linpro (extruded whole flaxseed and peas) or soybean meal. *Canadian Journal of Animal Science*, *84*(4), 681-688.

Waters, S. M., Kelly, J. P., O'Boyle, P., Moloney, A. P., & Kenny, D. A. (2009). Effect of level and duration of dietary n-3 polyunsaturated fatty acid supplementation on the transcriptional regulation of D ^{9}-desaturase in muscle of beef cattle. *Journal of Animal Science*, *87*, 244-252.

Wiseman, J., Redshaw, M. S., Jagger, S., Nute, G. R., & Wood, J. D. (2000). Influence of type and dietary rate of inclusion of oil on meat quality of finishing pigs. *Animal Science*, *70*(2), 307-315.

Wood, J. D., Enser, M., Fisher, A. V., Nute, G. R., Sheard, P. R., Richardson, R. I., Hughes, S. I., & Whittington, F. M. (2008). Fat deposition, fatty acid composition and meat quality: A review. *Meat Science*, *78*(4), 343-358.

Table 1. Ingredient composition and nutrient contents of experimental diets; Weeks 1 to 4

	Flax (%)			
Ingredients (% as fed)	0	5	10	15
Wheat	53.4	39.0	24.5	10.0
Barley	10.0	21.6	33.1	44.7
Soybean meal	17.0	15.3	13.5	11.8
Field pea	15.0	10.0	5.0	0.0
Co-extruded flaxseed and field pea[z]	0.0	10.0	20.0	30.0
Tallow	1.03	0.68	0.34	0.00
Di-calcium phosphate	0.85	0.83	0.82	0.80
Limestone	0.80	0.78	0.77	0.75
Vitamin premix[y]	0.50	0.50	0.50	0.50
Mineral premix[x]	0.50	0.50	0.50	0.50
Salt	0.50	0.50	0.50	0.50
L-Lysine-HCL	0.23	0.25	0.28	0.30
L-Threonine	0.10	0.10	0.10	0.11
DL-Methionine	0.060	0.067	0.073	0.080
Calculated nutrient content (as fed)				
DE[w] ($Mcal \cdot kg^{-1}$)	3.38	3.39	3.40	3.42
Dig. Lysine: DE ($g.Mcal\ DE^{-1}$)[v]	2.80	2.80	2.80	2.80
Crude protein (%)	20.6	20.0	19.4	18.0
Calcium, %	0.82	0.82	0.82	0.87
Phosphorus, total (%)	0.61	0.56	0.57	0.61

[z]Co-extruded 50% flaxseed and 50% field pea (Linpro; O&T Farms, Regina, Saskatchewan, Canada).

[y]Provided per kilogram of diet: vitamin A, 8,250 IU; vitamin D_3, 825 IU; vitamin E, 40 IU; niacin, 35 mg; D-pantothenic acid, 15 mg; riboflavin, 5 mg; menadione, 4 mg; folic acid, 2 mg; thiamine, 1 mg; D-biotin, 0.2 mg; and vitamin B_{12}, 25 μg.

[x]Provided per kilogram of diet: Zn, 100 mg as zinc sulfate; Fe, 80 mg as ferrous sulfate; Cu, 50 mg as copper sulfate; Mn, 25 mg as manganous sulfate; I, 0.50 mg as calcium iodate; and Se, 0.10 mg as sodium selenite.

[w]Digestible energy

[v]Other amino acids were formulated as a ratio to lysine (set at 100%): threonine, 62; methionine, 30; and tryptophan, 20 (NRC, 1998).

Table 2. Ingredient composition and nutrient contents of experimental diets; Weeks 5 to 8

Ingredients (% as fed)	Flax (%)			
	0	5	10	15
Wheat	44.2	31.1	18.1	5.0
Barley	20.2	30.9	41.6	52.3
Soybean meal	16.2	13.9	11.5	9.2
Field pea	15.0	10.0	5.0	0.0
Co-extruded flaxseed and field pea[z]	0.0	10.0	20.0	30.0
Tallow	1.00	0.67	0.33	0.00
Di-calcium phosphate	0.95	0.93	0.92	0.90
Limestone	0.80	0.78	0.77	0.75
Vitamin premix[y]	0.50	0.50	0.50	0.50
Mineral premix[x]	0.50	0.50	0.50	0.50
Salt	0.50	0.50	0.50	0.50
L-Lysine-HCL	0.12	0.16	0.19	0.23
L-Threonine	0.055	0.055	0.065	0.075
DL-Methionine	0.015	0.025	0.035	0.045
Calculated nutrient content (as fed)				
DE[w] ($Mcal \cdot kg^{-1}$)	3.34	3.35	3.37	3.38
Dig. Lysine: DE ($g.Mcal\ DE^{-1}$)[v]	2.55	2.54	2.53	2.52
Crude protein (%)	19.2	19.2	16.8	16.2
Calcium, %	0.86	0.88	0.79	0.72
Phosphorus, total (%)	0.64	0.66	0.60	0.58

[z]Co-extruded 50% flaxseed and 50% field pea (Linpro; O&T Farms, Regina, Saskatchewan, Canada).

[y]Provided per kilogram of diet: vitamin A, 8,250 IU; vitamin D_3, 825 IU; vitamin E, 40 IU; niacin, 35 mg; D-pantothenic acid, 15 mg; riboflavin, 5 mg; menadione, 4 mg; folic acid, 2 mg; thiamine, 1 mg; D-biotin, 0.2 mg; and vitamin B_{12}, 25 µg.

[x]Provided per kilogram of diet: Zn, 100 mg as zinc sulfate; Fe, 80 mg as ferrous sulfate; Cu, 50 mg as copper sulfate; Mn, 25 mg as manganous sulfate; I, 0.50 mg as calcium iodate; and Se, 0.10 mg as sodium selenite.

[w]Digestible energy

[v]Other amino acids were formulated as a ratio to lysine (set at 100%): threonine, 62; methionine, 30; and tryptophan, 20 (NRC, 1998).

Table 3. Ingredient composition and nutrient contents of experimental diets; Weeks 9 to 12

Ingredients (% as fed)	Flax (%)			
	0	5	10	15
Wheat	39.9	26.6	13.3	0.00
Barley	32.5	42.7	53.0	63.2
Soybean meal	8.70	7.13	5.57	4.00
Field pea	15.0	10.0	5.0	0.0
Co-extruded flaxseed and field pea[z]	0.0	10.0	20.0	30.0
Tallow	1.00	0.67	0.33	0.00
Di-calcium phosphate	0.50	0.48	0.47	0.45
Limestone	0.80	0.78	0.77	0.75
Vitamin premix[y]	0.50	0.50	0.50	0.50
Mineral premix[x]	0.50	0.50	0.50	0.50
Salt	0.50	0.50	0.50	0.50
L-Lysine-HCL	0.075	0.088	0.10	0.12
L-Threonine	0.005	0.005	0.005	0.005
DL-Methionine	0.000	0.000	0.000	0.000
Calculated nutrient content (as fed)				
DE[w] ($Mcal \cdot kg^{-1}$)	3.29	3.31	3.33	3.35
Dig. Lysine: DE ($g.Mcal\ DE^{-1}$)[v]	1.98	1.97	1.95	1.94
Crude protein (%)	16.9	16.4	15.3	15.0
Calcium, %	0.71	0.89	0.65	0.64
Phosphorus, total (%)	0.51	0.53	0.48	0.49

[z]Co-extruded 50% flaxseed and 50% field pea (Linpro; O&T Farms, Regina, Saskatchewan, Canada).

[y]Provided per kilogram of diet: vitamin A, 8,250 IU; vitamin D_3, 825 IU; vitamin E, 40 IU; niacin, 35 mg; D-pantothenic acid, 15 mg; riboflavin, 5 mg; menadione, 4 mg; folic acid, 2 mg; thiamine, 1 mg; D-biotin, 0.2 mg; and vitamin B_{12}, 25 µg.

[x]Provided per kilogram of diet: Zn, 100 mg as zinc sulfate; Fe, 80 mg as ferrous sulfate; Cu, 50 mg as copper sulfate; Mn, 25 mg as manganous sulfate; I, 0.50 mg as calcium iodate; and Se, 0.10 mg as sodium selenite.

[w]Digestible energy

[v]Other amino acids were formulated as a ratio to lysine (set at 100%): threonine, 62; methionine, 30; and tryptophan, 20 (NRC, 1998).

Table 4. Crude fat and fatty acid composition of diets

	Weeks 1-4; flax (%)				Weeks 5-8; flax (%)				Weeks 9-12; flax (%)			
Item	0	5	10	15	0	5	10	15	0	5	10	15
Crude fat ($g.kg^{-1}$)[z]	26.8	41.8	64.0	71.0	26.9	34.4	64.7	72.5	21.8	38.0	60.2	79.3
Fatty acid (%)												
16:0	20.6	15.8	11.2	8.8	19.0	12.4	11.0	8.5	19.8	13.9	10.8	8.4
9*c*-16:1	1.3	0.9	0.5	0.2	1.2	0.2	0.6	0.2	0.9	0.6	0.3	0.1
18:0	8.6	6.5	4.5	3.1	6.8	3.0	4.8	3.4	5.2	4.6	3.8	3.0
9*c*-18:1	26.1	22.8	19.5	17.2	25.3	18.8	22.0	20.0	23.8	22.5	21.4	20.9
18:2n-6	37.6	30.4	24.7	23.2	40.6	36.3	25.8	24.9	43.8	33.4	27.7	24.9
18:3n-3	5.2	22.7	39.0	47.0	6.5	28.2	34.9	42.0	5.9	24.2	34.9	41.7
11*c*-20:1	0.6	0.9	0.5	0.5	0.7	1.0	1.1	1.0	0.7	0.9	1.1	0.9

[z]Measured.

Table 5. Performance of grower-finisher pigs fed different levels of extruded flaxseed for different durations

Variable	Control	Diet (% flax)			Weeks			Gender		SEM[z]	*P* value		
		5	10	15	4	8	12	Gilt	Barrow		Diet	Weeks	Gender
Initial weight (kg)	31.1	30.8	30.9	31.4	30.9	31.2	31.0	30.7	31.3	1.48	0.31	0.74	0.08
Final weight (kg)	109.7	114.6	112.9	115.2	115.6[a]	115.7[a]	111.4[b]	110.0	118.5	2.09	0.36	0.02	<0.0001
ADG ($kg \cdot d^{-1}$)	0.94	1.00	0.98	1.00	1.01[a]	1.01[a]	0.96[b]	0.95	1.03	0.01	0.42	0.02	<0.0001
ADFI ($kg \cdot d^{-1}$)	2.46	2.60[a]	2.50[ab]	2.47[b]	2.58	2.55	2.45	2.33	2.72	0.03	0.01	0.06	<0.0001
Feed efficiency	0.38	0.39[b]	0.39[b]	0.41[a]	0.39	0.40	0.39	0.41	0.38	0.01	0.01	0.80	<0.0001

[z]Standard error of the mean.

[a-b]Means in rows with different letters are significantly different ($P < 0.05$)

No two or three-way interactions were observed ($P > 0.05$)

Table 6. Gender effects on the percent fatty acid composition of backfat

	Gender		SEM[z]	*P* value
Fatty acid (%)	Gilt	Barrow		
18:2n-6	12.0	11.4	0.28	0.03
18:3n-3	9.3	9.3	0.38	0.99
20:2n-6	0.53	0.50	0.009	0.02
20:3n-3	1.27	1.25	0.023	0.58
20:4n-6	0.16	0.15	0.004	0.04
20:5n-3	0.13	0.12	0.007	0.06
22:5n-3	0.30	0.31	0.009	0.34
22:6n-3	0.07	0.07	0.002	0.98
n-3	11.1	11.0	0.39	0.95
n-6	12.7	12.1	0.290	0.03
n-6/n-3	1.39	1.36	0.025	0.15
SFA	31.6	32.8	0.39	0.04
MUFA	43.9	43.3	0.62	0.22
PUFA	23.8	23.2	0.67	0.26

[z]Standard error of the mean

Table 7. Diet, feeding duration and diet by feeding duration effects on percentages of fatty acids in backfat

% Flax	Control	5			10			15			SEM[z]	*P* value		
Week		4	8	12	4	8	12	4	8	12		Diet	Weeks	Diet*Week
18:2n-6	9.6	10.1^{e}	10.9^{de}	10.6^{e}	10.1^{e}	11.9^{cd}	13.2^{ab}	11.7^{cd}	12.8^{bc}	14.0^{a}	0.3	<0.01	<0.01	0.01
18:3n-3	1.22	3.33^{f}	4.95^{e}	5.87^{e}	5.52^{e}	9.78^{c}	13.30^{b}	8.37^{d}	13.90^{b}	18.60^{a}	0.4	0.02	<0.01	<0.01
20:2n-6	0.46	0.47^{cd}	0.50^{bcd}	0.49^{cd}	0.46^{d}	0.54^{ab}	0.54^{ab}	0.51^{bcd}	0.51^{bc}	0.58^{a}	0.01	0.01	<0.01	0.1
20:3n-3	0.23	0.54^{f}	0.80^{e}	1.00^{d}	0.76^{e}	1.40^{c}	1.80^{b}	1.00^{d}	1.70^{b}	2.40^{a}	0.03	<0.01	<0.01	<0.01
20:4n-6	0.22	0.19^{ab}	0.18^{ab}	0.14^{d}	0.18^{bc}	0.15^{cd}	0.12^{d}	0.21^{a}	0.15^{d}	0.09^{e}	0.01	<0.01	<0.01	<0.01
20:5n-3	0.03	0.06^{e}	0.08^{d}	0.10^{cd}	0.07^{de}	0.12^{c}	0.19^{ab}	0.09^{d}	0.18^{b}	0.22^{a}	0.01	<0.01	<0.01	<0.01
22:5n-3	0.14	0.19^{g}	0.27^{ef}	0.29^{de}	0.22^{fg}	0.34^{cd}	0.42^{ab}	0.23^{fg}	0.36^{bc}	0.41^{ab}	0.01	<0.01	<0.01	0.07
22:6n-3	0.06	0.055	0.072	0.070	0.061	0.07	0.073	0.068	0.066	0.070	0.003	0.83	0.09	0.62
n-3	1.69	4.17^{f}	6.18^{e}	7.30^{e}	6.63^{e}	11.70^{c}	15.80^{b}	9.79^{d}	16.10^{b}	21.60^{a}	0.42	<0.01	<0.01	0.04
n-6	10.3	10.7^{e}	11.5^{de}	11.3^{e}	10.7^{e}	12.6^{cd}	13.9^{ab}	12.4^{cd}	13.4^{bc}	14.7^{a}	0.44	<0.01	<0.01	0.02
n-6/n-3	6.09	2.59^{a}	1.87^{b}	1.55^{c}	1.64^{c}	1.07^{e}	0.88^{f}	1.29^{d}	0.84^{f}	0.68^{g}	0.025	<0.01	<0.01	<0.01
SFA	36.2	35.6^{ab}	36.8^{ab}	34.9^{ab}	34.3^{b}	31.6^{cd}	29.2^{e}	31.8^{cd}	29.2^{de}	26.9^{e}	0.48	<0.01	<0.01	<0.01
MUFA	51.1	48.5^{ab}	44.8^{cd}	45.8^{bc}	47.6^{ab}	43.4^{d}	40.3^{e}	45.2^{cd}	40.5^{e}	36.3^{f}	0.67	<0.01	<0.01	0.02
PUFA	12.1	15.1^{e}	17.8^{d}	18.7^{d}	17.5^{d}	24.4^{c}	29.8^{b}	22.3^{c}	29.6^{b}	36.4^{a}	0.72	<0.01	<0.01	<0.01

[z]Standard error of the mean

[a-g]Means in rows with different letters are significantly different ($P < 0.05$)

Impact of feeding diets containing extruded flaxseed meal for an extended period on the carcass and meat quality of finishing swine

J.F. Patience, R.T. Zijlstra[1], A.D. Beaulieu, M. Dugan[2], P. Leterme and I.U. Haq

[1]University of Alberta, Edmonton, AB. [2]Agriculture and Agri-Food Canada Lacombe Research Centre, Lacombe, AB.,

ACKNOWLEDGEMENTS

The authors acknowledge with gratitude the financial support provided by Flax Canada and the Saskatchewan Agricultural Development Fund. We gratefully acknowledge the donation of LinPro from O&T Farms, SK. We also appreciate the strategic funding provided by Sask Pork, Alberta Pork, the Manitoba Pork Council and the Saskatchewan Agriculture and Food Development Fund.

EXECUTIVE SUMMARY

The role of alpha linolenic acid (ALA) in human health is gaining attention and there is an increasing demand for food products rich in ALA. Meat and meat products are low in ALA due to extensive use of feed ingredients low in ALA in animal diets. Studies have indicated that flaxseed has the potential to be used in swine diets to produce pork enriched with ALA. However, results are inconsistent, partly due to differences in basal diets, but also due to the lack of standardization of flaxseed extrusion conditions, differences in levels of flaxseed incorporation into the diet, and the length of feeding. The present study was designed to investigate the impact of feeding different levels of extruded flaxseed for different lengths of time on the enrichment and consistency of enrichment of ALA in pork. A blended product of peas and flaxseed (50:50) extruded under controlled conditions of temperature and pressure (LinPro) was used. Experimental diets in were based on wheat, barley and soybean meal.

The experiment was conducted on 96 pigs (48 ± 2 kg) fed two levels of flaxseed (5 and 10%) for 76 days. Performance (ADG, ADFI or FCE) was unaffected by either 5 or 10 % extruded flaxseed in the diet ($P <$ 0.05). Carcass lean yield increased from 56.96 to 58.34% as dietary flaxseed increased from 0 to 10% (P = 0.045). There was a decrease in carcass fat hardness from very hard to moderately soft with increasing inclusion of flaxseed in the diet ($P < 0.0001$). The ALA content in the outer and inner backfat increased with increasing levels of flaxseed. The results of both experiments indicate that extruded flaxseed can be included in grower and finisher diets up to 15% without any adverse effect on performance. Increasing either the flaxseed concentration or increasing the length of feeding improves the enrichment of ALA in the backfat of pigs. The consistency of ALA enrichment is improved by increasing the length of time that the flaxseed is fed.

INTRODUCTION

Omega-3 fatty acids are well recognized for their health benefits and deficiency may contribute to the prevalence of many diseases. There are three major omega 3 fatty acids, alpha-linolenic acid (ALA), eicosapentaenoic acid (EPA), and docosahexaenoic acid (DHA). The amount of ALA present in meat and meat products is low due to extensive use of feed ingredients deficient in ALA. The contribution of omega-3 fatty acids to improving human health has increased the demand for omega-3 enriched products, including pork. One of the options to produce omega-3 pork is through dietary manipulation by including feed ingredients rich in omega-3 in the pig's diet. Flaxseed, the richest plant source of ALA, (370 g ALA kg^{-1} fat, 460–710 g ALA kg^{-1} FA; Grossu and Iliescu, 1998), has gained attention as a dietary ingredient for swine. However, the high fat content may cause handling problems. Extruding flaxseed with field peas has been shown to alleviate these problems (Thacker et al., 2004). Flaxseed needs to be processed to ensure easy handling and a superior level of nutrient digestibility before inclusion into swine diets. An earlier study indicated that a blend of flax and peas (50:50) with single screw extrusion at 400 psi with no added water and a barrel temperature of 135 ^{0}C is the optimal for extrusion of flaxseed (Htoo et al., 2007; Appendix A). Linpro®, a commercial product of flaxseed and peas (50:50) extruded under the conditions as described by Htoo et al., 2007, was used in the following studies.

This project is the first large-scale research program in Canada to analyze opportunities for increasing the omega-3 fatty acid content in pork using optimally processed flaxseed. Similar attempts have been made in the past by to incorporate ground flaxseed into corn-based diets for grower-finisher pigs (Romans et al., 1995). However, corn, in contrast to wheat and barley contains large amounts of unsaturated fat. Mixing flaxseed, which also contains large amount of unsaturated fat, into corn-based diets resulted in the feeding of large amounts of unsaturated fat, and soft carcass. We hypothesized that including flaxseed in barley or wheat based diets, common feed ingredients on the prairies, should result in carcass fat that is firmer, and therefore less of a challenge during carcass handling or food processing.

This experiment was designed to study the impact of feeding diets containing different levels of flaxseed meal for different durations to grower and finisher pigs. The main objective of the study was to investigate the ALA enrichment and consistency of enrichment in the pork.

OBJECTIVES

The objectives of the experiments were:

- To determine the optimum combination of level and length of feeding extruded flaxseed meal to achieve a desired level and consistency of ALA in pork.
- To study the impact of an extended period of feeding different levels of extruded flaxseed meal on pig performance, carcass composition and meat quality.

MATERIALS AND METHODS

General

Barn and room preparation. The experiments were conducted at the Prairie Swine Centre, Saskatoon, SK. The experiments were conducted in two intensive rooms each having 76 individual pens, measuring 0.91 x 1.83 m (1.67 m^2). Floors are fully slatted. Each pen was equipped with a single space feeder at the front and a nipple drinker at the back. The pens were thoroughly cleaned before the assignment of

experimental treatments and pigs to the pens. The rooms have automatic exhaust, temperature and light controls. The rooms were maintained on a 14 hour light: 10 hour dark cycle. Assignment of pigs to pens was random.

Experimental diets. LinPro® a commercial product (O&T Farms, Regina, Saskatchewan, Canada) containing a 50:50 mixture of flaxseed and field peas, was used as the flaxseed source (Table 1). Based on a preliminary experiment (Htoo et al. 2007) it was extruded by a single screw extrusion at 400 psi with no added water and a barrel temperature of 135 ^{0}C. Experimental diets were based on wheat, barley and soybean meal (Experiment 1, Tables 2, 3, 4; Experiment 2, Tables 5, 6, 7). Peas were added to the control diets and the quantities were decreased to equal the quantities of peas supplied by the mixture of extruded flaxseed and peas. The diets were formulated in three phases to meet the nutrient requirement of the pigs as they grew.

Animals and treatment randomization

The experiment utilized 96 pigs (48 gilts and 48 barrows) with an initial body weight of 48 ± 2 kg (mean ± SD). Dietary treatments were 3 levels of extruded flaxseed (0, 5 and 10%) fed for 76 days. All the available pigs from one week's farrowing were weighed, selected and assigned to treatments. The process was repeated each week for four weeks. The commencement of the experiment was staggered over 4 weeks in order to handle the shipment and carcass evaluation. Thus, 4 gilts and 4 barrows per treatment started the experiment on Tuesday of week 1, another group of 4 gilts and 4 barrows on Tuesday of week 2, another group on week 3 and the last group on week 4. Therefore, 24 pigs were shipped to Lacombe Research Centre, Alberta each week for 4 weeks at the end of the experiment (on 76th day) for detailed carcass analysis.

The experiment was conducted as a completely randomized design with a factorial arrangement of treatments (3 extruded flaxseed levels by 2 genders). There were 4 pigs on each of the treatments per gender per rep and all the treatments were replicated four times.

Data and Sample Collection

Weight of the pigs and feed added and removed was recorded every 14 days and ADG and ADFI was calculated. Feed conversion (G:F) was also calculated from these data.

On the 76th day of the experiment the pigs were shipped to Lacombe Research Centre for detailed carcass analysis and meat evaluation using simulated commercial conditions. This included lean yield, determined by full cut-out, and estimated yield by optical probe. Fatty acid analysis was conducted on the centre cut loin, the picnic and the butt as well as the ham, the ribs, and the commercially trimmed and squared belly (data to be reported at a later date). Other measurements on the loin included pH, temperature, objective and subjective colour scores, marbling, structure, drip loss, shear strength, dry matter, total fat and fat hardness.

Statistical Analysis.

The data was analyzed using the MIXED procedure within SAS. Pig was considered as an experimental unit. The statistical model included flaxseed level, length of feeding, gender and the interactions in experiment 1. An initial analysis examined the main effects of flaxseed inclusion, length of feeding and the interactions. The control treatment was excluded from this analysis. The control treatment was then

compared, using the PDiff option within the MIXED procedure, to the other 9 treatments. The statistical model used for experiment 2 included flaxseed levels, gender and interactions.

RESULTS AND DISCUSSION

The *P* values presented in Table 14 indicated that there was no interaction between diet and gender for ADF, ADFI and G:F. There was a numerical decrease in ADG from 0.99 to 0.95 kg per day ($P = 0.149$, Table 15) and ADFI from 3.17 to 3.06 kg per day ($P = 0.181$, Table 15) as the level of extruded flaxseed in the diet increased from 0 to 10%. The G:F ratio remained unchanged ($P = 0.774$, Table 15) with increasing levels of extruded flaxseed in the diet. The Barrows had significantly higher ADG and ADFI as compared to the gilts (Table 16). It is clear from the results of the study that extruded flaxseed can be included in the grower and finisher diets without adverse effects on pig performance.

Live pigs were shipped to Lacombe Research Centre, Alberta, Canada for detailed carcass analysis on the 76th day of the experiment. Pigs were slaughtered and dressed using simulated commercial conditions.

Hot dressing percentage decreased from 84.81 to 83.69 as the inclusion rates of flaxseed increased from 0 to 10% in the diet ($P = 0.0001$, Table 17). The lean yield increased with increasing levels of flaxseed ($P = 0.04$, Table 17), and was higher in gilts compared to barrows ($P < 0.0001$, Table 17). This is in contrast to Romans et al. (1995) who observed no effect of 15% flaxseed for 25 days prior to slaughter on carcass traits.

There was a decrease in fat hardness from 83.57 (very hard) to 55.67 (moderately soft) with increasing levels of flaxseed in the diet ($P < 0.0001$, Table 17). Barrows had a firmer fat than gilts ($P < 0.0001$, Table 17). There were no interactions between gender and flaxseed for hot carcass dressing percentage, lean yield or fat hardness (Table 18). The gilts had less carcass fat ($P < 0.0001$, Table 19) than barrows. Effects of treatment on carcass moisture were due to combined effects of gender and levels of flaxseed (Table 20). There were no differences in cook loss and cook time of the pork from either gender or due to levels of flaxseed ($P > 0.05$; Table 19). Feeding 0 to 10% flaxseed had no effect on the percent of picnic, hock, butt, ham, loin or belly ($P > 0.10$; Table 21). The gilts had increased proportions of ham and hocks compared to barrows ($P < 0.05$; Table 21) while the barrows had increased proportions of belly ($P < 0.01$; Table 21) however, there was no interaction of gender by treatment for these primal cuts ($P > 0.10$; Table 22).

Surprisingly, the intramuscular fat content of the picnic, hock, ham, loin and butt decreased and the proportion of lean increased with increasing levels of flaxseed and ($P < 0.05$; Table 23). Barrows had higher intramuscular fat than gilts in the picnic, ham, loin and butt ($P < 0.01$; Table 23). Except for the proportion of lean in the picnic, where the which increased in barrows, but not in gilts, there was no interaction of gender and treatment on the proportions of lean, bone, or fat in the primal cuts ($P > 0.01$; Table 24).

The total intramuscular fat for all the lean cuts decreased from 57.43 to 48.84 g/kg with increasing levels of flaxseed ($P < 0.0001$, Table 25). Barrows had higher total intramuscular fat (57.37 g/kg) than gilts (46.85 g/kg, $P < 0.0001$, Table 25). Total lean increased from 613.94 to 633.05 g/kg with increasing levels of flaxseed from 0 to 10% ($P = 0.0339$, Table 25). The gilts had higher total lean from all the lean cuts (647.59 g/kg) than barrows (603.51 g/kg, $P < 0.0001$, Table 25). There was no interaction between gender and flaxseed levels for total intramuscular fat or total lean ($P > 0.05$; Table 26).

The ALA content of inner backfat (as % of total fat) increased from 0.690 to 13.715 with increasing levels of flaxseed in the diets ($P < 0.0001$, Table 27) and ALA content of outer backfat increased from

1.008 to 15.213 ($P < 0.0001$, Table 27). There was no difference in the ALA content of inner and outer backfat between gilts and barrows (Table 27). Increasing flaxseed levels from 0 to 10% decreased the n-6/n-3 ratio from 8.254 to 0.751 in the inner back fat ($P < 0.0001$, Table 27) and from 7.475 to 0.790 in the outer backfat ($P < 0.0001$, Table 27).

SUMMARY

Flaxseed, extruded under conditions for optimal amino acid digestibility, can be included at up to 15% in the diet of growing-finishing pigs without adverse effects on growth rate and an improvement in feed efficiency.

The content of ALA in subcutaneous backfat is increased linearly by increasing the amount of flaxseed in the diet (from 0 to 15%) and the time it is fed (from 0 to 12 weeks pre-slaughter). Moreover, these effects were additive, the highest proportion of ALA in backfat was when a diet containing 15% flaxseed was fed for 12 weeks.

The consistency of the enrichment of backfat with ALA is improved by the length of feeding, not by increasing amounts of flaxseed in the diet.

The standard to qualify as an "omega-3 enriched" product in Canada is 300 mg of omega-3 per 100 gram serving. To qualify for a source claim on at least 90% of the samples of "lean pork" a producer would need to include 5% flaxseed in the diet for at least 12 weeks or 10 to 15% flaxseed for 8 weeks.

Except for the effects on fat hardness, 10% dietary flaxseed for 11 weeks had minimal effects on carcass traits. Increasing dietary flaxseed from 0 to 10 % of the diet resulted in increased proportions of lean, and decreased intramuscular fat.

CONCLUSIONS

Omega-3 enriched pork can likely be obtained by the inclusion of 5% flaxseed in the diet for 12 weeks, or 10% for 84 weeks. This can be accomplished without detrimental effects on either performance or carcass quality.

Table 1. Nutrient profile of LinPro

Nutrients	Contents
Crude protein %	20.25
Crude fat %	20.25
Crude fiber %	5.40
DE kcal/kg	4637
Calcium %	0.15
Phosphorous %	0.45
Digestible lysine %	0.95
Digestible methionine %	0.27
Digestible tryptophane %	0.27
Linoleic acid %	3.15
Linolenic acid %	11.10
Oleic acid %	3.45

Source: O & T Farms, Regina, Saskatchewan.

Table 2 Ingredient composition and nutrient contents of experimental diets; Phase 1

Ingredients (%, as fed)	Flax 0%	Flax 5%	Flax 10%
Wheat	50.016	30.008	10.000
Barley	12.800	28.478	44.155
Soybean meal	23.000	22.900	22.800
Field peas	10.000	5.000	0.000
Linpro[a]	0.000	10.000	20.000
Tallow	0.899	0.450	0.000
Di-calcium phosphate	0.850	0.800	0.750
Limestone	0.800	0.775	0.750
PSCI Vitamin mix[b]	0.500	0.500	0.500
PSCI Mineral mix[c]	0.500	0.500	0.500
Salt	0.500	0.500	0.500
L-Lysine-HCL	0.085	0.063	0.040
L-Threonine	0.040	0.020	0.000
DL-Methionine	0.010	0.008	0.005
Nutrients (as fed)			
DE[d] (Mcal/kg)	3.374	3.375	3.375
Dig. Lysine: DE[d] (g/Mcal DE)	2.797	2.795	2.793
Crude protein[e], %	21.930	22.130	21.97
AID lysine[d], %	0.944	0.943	0.943
AID threonine[d], %	0.596	0.595	0.594
AID methionine[d], %	0.263	0.267	0.271
AID tryptophan[d], %	0.203	0.204	0.206
Calcium[e], %	0.750	0.760	0.700
Total phosphorous[e], %	0.590	0.560	0.570

[a] Commercial product (O&T farms, Regina, Saskatchewan, Canada) containing 50:50 extruded mixture of flaxseed and field peas.

[b]Provided per kilogram of diet: vitamin A, 8,250 IU; vitamin D_3, 825 IU; vitamin E, 40 IU; niacin, 35 mg; D-pantothenic acid, 15 mg; riboflavin, 5 mg; menadione, 4 mg; folic acid, 2 mg; thiamine, 1 mg; D-biotin, 0.2 mg; and vitamin B_{12}, 25 µg.

[c]Provided per kilogram of diet: Zn, 100 mg as zinc sulfate; Fe, 80 mg as ferrous sulfate; Cu, 50 mg as copper sulfate; Mn, 25 mg as manganous sulfate; I, 0.50 mg as calcium iodate; and Se, 0.10 mg as sodium selenite.

[d]Calculated

[e]Measured

Table 3 Ingredient composition and nutrient contents of experimental diets; Phase 2

Ingredients (%, as fed)	Flax 0%	Flax 5%	Flax 10%
Wheat	48.235	30.215	12.194
Barley	20.800	35.161	49.521
Soybean meal	16.500	15.750	15.000
Field peas	10.000	5.000	0.000
Linpro[a]	0.000	10.000	20.000
Tallow	1.000	0.500	0.000
Di-calcium phosphate	0.950	0.900	0.850
Limestone	0.800	0.775	0.750
PSCI Vitamin mix[b]	0.500	0.500	0.500
PSCI Mineral mix[c]	0.500	0.500	0.500
Salt	0.500	0.500	0.500
L-Lysine-HCL	0.150	0.145	0.140
L-Threonine	0.055	0.045	0.035
DL-Methionine	0.010	0.010	0.010
Nutrients (as fed)			
DE[d] (Mcal/kg)	3.334	3.335	3.336
Dig. Lysine/DE[d] (g/Mcal DE)	2.552	2.547	2.543
Crude protein[e], %	19.170	18.620	19.080
AID lysine[d], %	0.851	0.849	0.848
AID threonine[d], %	0.535	0.536	0.537
AID methionine[d], %	0.238	0.242	0.246
AID tryptophan[d], %	0.175	0.175	0.174
Calcium[e], %	0.610	0.740	0.630
Total phosphorous[e], %	0.560	0.590	0.530

[a] Commercial product (O&T farms, Regina, Saskatchewan, Canada) containing 50:50 extruded mixture of flaxseed and field peas.

[b]Provided per kilogram of diet: vitamin A, 8,250 IU; vitamin D_3, 825 IU; vitamin E, 40 IU; niacin, 35 mg; D-pantothenic acid, 15 mg; riboflavin, 5 mg; menadione, 4 mg; folic acid, 2 mg; thiamine, 1 mg; D-biotin, 0.2 mg; and vitamin B_{12}, 25 μg.

[c]Provided per kilogram of diet: Zn, 100 mg as zinc sulfate; Fe, 80 mg as ferrous sulfate; Cu, 50 mg as copper sulfate; Mn, 25 mg as manganous sulfate; I, 0.50 mg as calcium iodate; and Se, 0.10 mg as sodium selenite.

[d]Calculated

[e]Measured

Table 4 Ingredient composition and nutrient contents of experimental diets; Phase 3

Ingredients (%, as fed)	Control	Flax 5	Flax 10
Wheat	44.950	28.988	13.026
Barley	33.000	46.380	59.759
Soybean meal	8.100	6.200	4.300
Field peas	10.000	5.000	0.000
Linpro[a]	0.000	10.000	20.000
Tallow	1.000	0.500	0.000
Di-calcium phosphate	0.550	0.525	0.500
Limestone	0.750	0.725	0.700
PSCI Vitamin mix[b]	0.500	0.500	0.500
PSCI Mineral mix[c]	0.500	0.500	0.500
Salt	0.500	0.500	0.500
L-Lysine-HCL	0.125	0.155	0.185
L-Threonine	0.025	0.028	0.030
DL-Methionine	0.000	0.000	0.000
Nutrients (as fed)			
DE[d] (Mcal/kg)	3.288	3.289	3.280
Dig. Lysine/DE[d] (g/Mcal DE)	1.972	1.972	1.972
Crude protein[d], %	18.510	16.88	16.580
AID lysine[d], %	0.648	0.649	0.649
AID threonine[d], %	0.409	0.409	0.409
AID methionine[d], %	0.197	0.197	0.197
AID tryptophan[d], %	0.140	0.136	0.131
Calcium[e], %	0.620	0.550	0.500
Total phosphorous[e], %	0.500	0.480	0.470

[a] Commercial product (O&T farms, Regina, Saskatchewan, Canada) containing 50:50 extruded mixture of flaxseed and field peas.

[b]Provided per kilogram of diet: vitamin A, 8,250 IU; vitamin D_3, 825 IU; vitamin E, 40 IU; niacin, 35 mg; D-pantothenic acid, 15 mg; riboflavin, 5 mg; menadione, 4 mg; folic acid, 2 mg; thiamine, 1 mg; D-biotin, 0.2 mg; and vitamin B_{12}, 25 μg.

[c]Provided per kilogram of diet: Zn, 100 mg as zinc sulfate; Fe, 80 mg as ferrous sulfate; Cu, 50 mg as copper sulfate; Mn, 25 mg as manganous sulfate; I, 0.50 mg as calcium iodate; and Se, 0.10 mg as sodium selenite.

[d]Calculated

[e]Measured

Table 5. Performance of grower-finisher pigs fed on different levels of extruded flaxseed

	Extruded flaxseed meal, %				
	0	**5**	**10**	**SEM**	***P***
Initial body weight (kg)	48.2	47.9	47.8	0.37	0.731
Final body weight (kg)	123.6	120.1	120.3	1.33	0.124
Weight gain (kg/d)	0.991	0.951	0.954	0.016	0.149
Feed consumption (kg/d)	3.169	3.057	3.058	0.049	0.181
G:F (kg/kg)	0.314	0.310	0.313	0.004	0.774

Table 6 Performance of gilts and barrows fed on different levels of extruded flaxseed meal.

	Average daily weight gain, kg	**Average daily feed intake, kg**	**G:F**
Gilt	0.9135^{b}	2.8760^{b}	0.3175^{a}
Barrow	1.0173^{a}	3.3130^{a}	0.3079^{b}
SEM	0.0130	0.0401	0.0034
P	0.0001	0.0001	0.0504

Table 7. The P values of different performance parameters of grower finisher pigs

	P values		
	Average daily gain, kg	**Average daily feed intake, kg**	**G:F ratio**
Diet	0.1485	0.1805	0.7740
Gender	0.0001	0.0001	0.0504
Block	0.1587	0.2696	0.0658
Diet*Gender	0.7578	0.6255	0.5336
Block*Diet	0.7404	0.0554	0.0861
Block*Gender	0.0472	0.5302	0.0288
Block*Diet*Gender	0.2100	0.9441	0.1633

Table 8 Effect of feeding extruded flaxseed on the carcass of grower finisher pigs

	Flaxseed, %					Gender			
	0	5	10	SEM	P	Gilts	Barrows	SEM	P
Plant weight, kg	117.75	114.40	114.92	1.40	0.1672	111.77[b]	119.61[a]	1.17	<0.0001
Left side cooler loss, %	2.54	2.62	2.51	0.18	0.2359	2.62[a]	2.50[b]	0.18	0.0371
Right side cooler loss, %	2.64	2.68	2.58	0.15	0.4005	2.66	2.61	0.14	0.3090
Cooler loss, %	2.59	2.65	2.55	0.16	0.1688	2.64	2.55	0.16	0.0520
Commercial hot weight, kg	99.85[a]	96.36[b]	96.15[b]	1.14	0.0309	93.96[b]	100.95[a]	0.94	<0.0001
Hot dressing, %	84.81[a]	84.23[b]	83.68[c]	0.19	0.0001	84.09	84.39	0.16	0.1518
Estimated Lean Yield, %	60.40	60.80	60.94	0.27	0.3431	61.61[a]	59.82[b]	0.22	<0.0001
Lean Yield[1], %	56.96[b]	58.07[ab]	58.34[a]	0.43	0.0446	59.26[a]	56.32[b]	0.36	<0.0001
Grade Lean Yield[2], %	58.11	59.02	59.30	0.41	0.0804	60.14[a]	57.48[b]	0.35	<0.0001
Fat Hardness[3]	83.57[a]	71.02[b]	55.67[c]	2.38	<0.0001	65.78[b]	74.40[a]	2.24	<0.0001

[1]Estimated by the destron probe.
[2]Grade lean yield = cutout lean + intramuscular or seam fat.
[3]Measured with durometer and readings were followed as:
Less than 16 = Extremely soft.
16 – 40 = Very soft
40 – 56 = Moderately soft
56 – 66 = Slightly soft
66 – 74 = Slightly hard
74 – 79 = Moderately hard
79 – 84 = Very hard
More than 84 = Extremely hard

Table 9. Interaction of gender and flaxseed level on the carcass quality of grower finisher pigs

	Gilts			Barrows				
Flaxseed, %	**0**	**5**	**10**	**0**	**5**	**10**	SEM	P value
Plant weight, kg	112.81	110.94	111.56	122.69	117.87	118.28	1.93	0.6455
Left side cooler loss, %	2.64	2.71	2.49	2.45	2.53	2.53	0.19	0.1590
Right side cooler loss, %	2.77	2.67	2.56	2.52	2.69	2.61	0.15	0.0808
Cooler loss, %	2.70	2.69	2.53	2.48	2.61	2.57	0.17	0.0594
Commercial hot weight, kg	95.43	93.26	93.18	104.27	99.46	99.13	1.58	0.5935
Hot dressing, %	84.63	84.09	83.55	84.99	84.37	83.81	0.26	0.9758
Estimated Lean Yield, %	61.68	61.37	61.77	59.12	60.23	60.10	0.38	0.1743
Lean Yield[1], %	59.14	59.03	59.60	54.77	57.11	57.09	0.60	0.0942
Grade Lean Yield[2], %	60.10	59.91	60.41	56.13	58.14	58.18	0.56	0.1085
Fat Hardness[3]	77.94	67.08	52.31	89.20	74.97	59.04	2.75	0.4860

[1]Estimated by the destron probe.
[2]Grade lean yield = cutout lean + intramuscular or seam fat.
[3]Measured with durometer and readings were followed as:
Less than 16 = Extremely soft.
16 – 40 = Very soft
40 – 56 = Moderately soft
56 – 66 = Slightly soft
66 – 74 = Slightly hard
74 – 79 = Moderately hard
79 – 84 = Very hard
More than 84 = Extremely hard

Table 10. Effect of feeding extruded flaxseed on the carcass quality of grower finisher pigs

	Flaxseed, %					Gender			
	0	5	10	SEM	P	Gilts	Barrows	SEM	P
pH and Temperature (°C)									
pH, 45 minutes	6.26	6.26	6.27	0.02	0.8114	6.25	6.28	0.01	0.2708
pH, 48 hours	5.54[b]	5.63[a]	5.61[a]	0.02	0.0224	5.58	5.61	0.02	0.3552
Temp, 45 minutes	40.2	40.2	40.2	0.08	0.7968	40.2	40.2	0.07	0.6896
Subjective Measurements									
Color	3	3	3	0.07	0.7600	3	3	0.06	0.9613
Structure	3	3	3	0.06	0.9962	3	3	0.05	0.6831
Objective Measurements									
L[1]	52.17[a]	49.66[b]	49.80[b]	0.57	0.0034	49.7	51.11	0.47	0.0907
Chroma[2]	10.20[a]	9.09[b]	8.96[b]	0.32	0.0018	9.01[b]	9.82[a]	0.29	0.0092
Hue[3]	29.38[a]	26.64[b]	26.14[b]	0.88	0.0224	26.25[b]	28.52[a]	0.72	0.0277
Shear, kg	5.06	5.78	5.52	0.38	0.0633	5.62	5.29	0.36	0.1796
Cookloss, mg.g-1	162.21	166.57	165.47	3.59	0.6723	167.96	161.55	2.93	0.1258
Cooktime, sec.g-1	6.61	7.45	7.03	0.42	0.1435	6.70	7.36	0.38	0.0603
Driploss, mg.g-1	36.43[a]	30.12[ab]	28.73[b]	2.28	0.0429	30.99	32.53	1.86	0.5610
Proximate Analysis									
Lean (mg.g-1)	NA								
Moisture	738.56[b]	742.14[a]	739.89[ab]	1.67	0.0270	742.42[a]	737.97[b]	1.59	<0.0001
Fat	26.35	22.77	24.69	2.14	0.1356	21.19[b]	28.02[a]	2.02	<0.0001
Proximate Analysis 20% Fat (mg.g-1) (used for taste panel)									
Moisture	633.85	630.93	630.43	3.57	0.6878	634.58	628.90	3.11	0.1080
Fat	163.18	171.11	170.80	5.46	0.2622	165.29	171.43	4.98	0.1725

[1]Bigger number = Lighter
[2]Bigger number = More intense color
[3]Bigger number = More yellow, Lower number = More red

Table 11. Interaction of gender and flaxseed level on the carcass quality of grower finisher pigs

	Gilts			Barrows				
Flaxseed, %	**0**	**5**	**10**	**0**	**5**	**10**	**SEM**	**P value**
pH and Temperature (°C)								
pH, 45 minutes	6.27	6.24	6.25	6.25	6.28	6.29	0.02	0.3495
pH, 48 hours	5.56	5.59	5.61	5.53	5.68	5.62	0.03	0.1630
Temp, 45 minutes	40.3	40.2	40.2	40.1	40.3	40.2	0.11	0.5902
Subjective Measurements								
Color	3	3	3	3	3	3	0.10	0.0659
Structure	3	3	3	3	3	3	0.08	0.1308
Objective Measurements								
L[1]	50.75	50.08	49.09	53.59	49.24	50.50	0.81	0.0795
Chroma[2]	9.54	9.18	8.32	10.86	8.99	9.60	0.42	0.0770
Hue[3]	27.34	26.75	24.66	31.42	26.52	27.62	1.24	0.2058
Shear, kg	5.34	5.58	5.95	4.78	5.98	5.10	0.44	0.1071
Cookloss, mg.g-1	167.62	169.34	166.91	156.80	163.81	164.03	5.08	0.7269
Cooktime, sec.g-1	6.54	7.02	6.55	6.68	7.87	7.51	0.51	0.5736
Driploss, mg.g-1	33.02	32.45	27.50	39.84	27.80	29.95	3.23	0.2091
Proximate Analysis Lean (mg.g-1)								
Moisture	742.11[a]	742.30[a]	742.86[a]	735.01[b]	741.98[a]	736.92[b]	1.91	0.0264
Fat	22.35	21.57	19.64	30.35	23.97	29.74	2.48	0.0862
Protein	Not available[4]							
Proximate Analysis 20% Fat (mg.g-1) for taste panel								
Moisture	635.97	634.34	633.42	631.73	627.53	627.43	4.68	0.9540
Fat	162.76	167.61	165.51	163.59	174.62	176.08	0.67	0.6639

[1]Bigger number = Lighter
[2]Bigger number = More intense color
[3]Bigger number = More yellow, Lower number = More red
[4]Protein data not available at the time of the report

Table 12. Effect of feeding flaxseed on the primal rough weights (% of side weight) of grower finisher pigs

	Flaxseed, %					*Gender*		SEM	P
	0	5	10	SEM	P	Gilts	Barrows		
Picnic	10.24	10.18	10.23	0.15	0.9214	10.13	10.30	0.13	0.2082
Hock	2.37	2.44	2.33	0.08	0.2972	2.44[a]	2.32[b]	0.08	0.0323
Butt	10.48	10.55	10.48	0.14	0.8661	10.45	10.56	0.12	0.3769
Ham	25.78	26.21	26.17	0.22	0.1445	26.52[a]	25.59[b]	0.20	<0.0001
Loin	26.17	25.83	25.70	0.26	0.3958	25.80	26.00	0.22	0.4846
Belly	18.74	18.61	18.85	0.17	0.5605	18.47[b]	19.00[a]	0.14	0.0047

Table 13. Interactive impact of gender and flaxseed on the primal rough weights (% of side weight) of grower finisher pigs

	Gilts			Barrows				
Flaxseed, %	**0**	**5**	**10**	**0**	**5**	**10**	**SEM**	**P value**
Picnic	10.19	10.02	10.19	10.29	10.33	10.27	0.18	0.7401
Hock	2.48	2.49	2.34	2.26	2.38	2.32	0.10	0.3017
Butt	10.44	10.48	10.43	10.52	10.63	10.53	0.17	0.9792
Ham	26.50	26.51	26.54	25.07	25.91	25.80	0.28	0.1778
Loin	25.92	25.79	25.68	26.42	25.87	25.72	0.37	0.7842
Belly	18.29	18.48	18.65	19.19	18.75	19.06	0.23	0.3275

Table 14. Effect of feeding extruded flaxseed on the composition (g/kg) of the primal cuts of grower and finisher pigs

	Flaxseed %					Gender			
	0	5	10	SEM	P value	Gilts	Barrows	SEM	P value
Picnic									
Lean	670.05[b]	688.07[a]	686.81[a]	5.04	0.0217	700.59[a]	662.70[b]	4.12	<0.0001
Bone	81.74	83.21	83.12	1.45	0.7233	84.38[a]	81.00[b]	1.18	0.0464
Subcutaneous Fat	148.11	141.92	141.99	4.16	0.4835	130.54[b]	157.48[a]	3.40	<0.0001
Body Cavity Fat	9.41	9.99	9.55	0.67	0.8220	9.34	9.96	0.55	0.4320
Intrarmuscular Fat	90.69[a]	76.72[b]	78.52[b]	2.98	<0.0001	75.15[b]	88.81[a]	2.66	<0.0001
Hock									
Lean	394.54[b]	406.65[a]	403.92[ab]	4.28	0.0385	410.26[a]	393.14[b]	3.78	<0.0001
Bone	353.94	349.05	352.58	3.76	0.5931	348.90	354.82	3.18	0.1422
Subcutaneous Fat	206.38	206.88	205.87	4.41	0.9833	203.19	209.57	3.80	0.1574
Intramuscular Fat	45.13[a]	37.46[b]	37.62[b]	2.8	0.0261	37.65	42.50	2.48	0.0659
Ham									
Lean	662.04	667.25	671.43	4.84	0.3877	681.30[a]	652.51[b]	3.95	<0.0001
Bone	85.74	86.56	86.44	1.15	0.8627	86.03	86.46	0.94	0.7494
Subcutaneous Fat	212.06	211.05	204.54	5.23	0.4976	197.78[b]	220.65[a]	4.40	0.0001
Body Cavity Fat	3.80	4.20	3.95	0.39	0.6491	3.96	4.01	0.35	0.8765
Intramuscular Fat	36.36[a]	30.92[c]	33.64[b]	1.22	0.0005	30.92[b]	36.35[a]	1.10	<0.0001
Loin									
Lean	548.00[b]	568.06[a]	570.77[a]	6.93	0.0437	591.63[a]	532.93[b]	5.66	<0.0001
Bone	121.48	123.97	125.41	3.41	0.4288	126.82[a]	120.42[b]	3.18	0.0123
Subcutaneous Fat	273.69	258.93	255.91	6.99	0.1456	236.54[b]	289.15[a]	5.78	<0.0001
Body Cavity Fat	12.57	12.00	11.07	0.71	0.1163	10.59[b]	13.17[a]	0.65	<0.0001
Intramuscular Fat	44.26[a]	37.05[b]	36.83[b]	1.65	0.0008	34.43[b]	44.33[a]	1.39	<0.0001
Butt									
Lean	614.07[b]	638.60[a]	644.16[a]	7.80	0.0012	654.66[a]	609.89[b]	7.00	<0.0001
Bone	44.38	42.55	41.83	1.15	0.2736	43.43	42.41	0.94	0.4477
Subcutaneous Fat	235.34	226.85	221.22	5.13	0.1281	213.97[b]	241.64[a]	4.27	<0.0001
Intramuscular Fat	106.21[a]	92.17[b]	92.79[b]	3.36	<0.0001	87.94[b]	106.17[a]	3.06	<0.0001
Belly, skinned and trimmed	513.76	505.88	518.13	5.95	0.2476	504.44[b]	520.74[a]	5.14	0.0079
Ribs	198.75	209.60	196.15	4.80	0.0625	207.17a	195.83[b]	4.14	0.0216

Table 15. Interactive impact of feeding extruded flaxseed on the primal breakdown (g/kg) of grower and finisher pigs

	Gilts			Barrows				
Flaxseed, %	**0**	**5**	**10**	**0**	**5**	**10**	**SEM**	**P value**
Picnic								
Lean	699.45[a]	702.22[a]	700.09[a]	640.64[c]	673.91[b]	673.54[b]	7.13	0.0430
Bone	82.88	85.05	85.21	80.60	81.37	81.02	2.05	0.8900
Subcutaneous Fat	126.44	131.81	133.37	169.79	152.04	150.62	5.89	0.0566
Body Cavity Fat	8.66	9.63	9.75	10.17	10.35	9.36	0.95	0.6039
Intramuscular Fat	82.57	71.29	71.59	98.80	82.16	85.46	3.79	0.7219
Hock								
Lean	407.51	413.17	410.11	381.57	400.12	397.74	5.50	0.2961
Bone	350.62	343.30	352.78	357.27	354.81	352.39	5.11	0.4781
Subcutaneous Fat	197.76	210.31	201.50	215.00	203.45	210.24	5.87	0.0904
Intramuscular Fat	44.11	33.23	35.62	46.16	41.70	39.63	3.60	0.5913
Ham								
Lean	684.38	677.29	682.24	639.70	657.21	660.63	6.84	0.1360
Bone	86.76	85.72	85.62	84.71	87.40	87.26	1.63	0.4254
Subcutaneous Fat	191.41	203.48	198.46	232.71	218.62	210.62	7.16	0.0722
Body Cavity Fat	3.94	3.87	4.07	3.67	4.54	3.83	0.50	0.4728
Intramuscular Fat	33.51	29.65	29.61	39.21	32.19	37.66	1.54	0.1232
Loin								
Lean	585.41	592.59	596.88	510.59	543.52	544.67	9.80	0.3613
Bone	128.83	126.06	125.57	114.13	121.88	125.26	4.04	0.0557
Subcutaneous Fat	237.30	236.09	236.22	310.09	281.77	275.61	9.76	0.1862
Body Cavity Fat	11.26	10.96	9.55	13.87	13.04	12.59	0.88	0.8023
Intramuscular Fat	37.20	34.30	31.78	51.32	39.80	41.87	2.24	0.1403
Butt								
Lean	646.33	654.74	662.91	581.81	622.46	625.41	9.81	0.1268
Bone	44.75	43.89	41.64	44.01	41.22	42.01	1.63	0.6427
Subcutaneous Fat	215.11	215.55	211.26	255.57	238.15	231.19	7.11	0.2792
Intramuscular Fat	93.81	85.83	84.19	118.61	98.52	101.39	4.11	0.1974
Belly, skinned and trimmed	508.58	493.64	511.10	518.93	518.13	525.16	7.90	0.6119
Ribs	209.34	212.34	199.83	188.16	206.87	192.47	6.37	0.3549

Table 16. Effect of feeding extruded flaxseed on the totals of lean cuts[1] (g/kg) of grower and finisher pigs

	Flaxseed, %					Gender			
	0	5	10			Gilts	Barrows	SEM	P vlaue
Total Lean	613.94[b]	629.65[a]	633.05[a]	5.46	0.0339	647.59[a]	603.51[b]	4.46	<0.0001
Total Bone	92.13	93.09	93.33	1.42	0.6998	94.28[a]	91.42[b]	1.28	0.0222
Total Subcutaneous Fat	229.19	221.15	216.82	5.21	0.2333	204.74[b]	240.03[a]	4.26	<0.0001
Total Body Cavity Fat	7.31	7.23	6.75	0.34	0.2123	6.54[b]	7.65[a]	0.31	0.0001
Total Intramuscular Fat	57.43[a]	48.84[b]	50.06[b]	1.66	<0.0001	46.85[b]	57.37[a]	1.50	<0.0001
Total Dissectible Fat	293.93[a]	277.30[ab]	273.63[b]	5.97	0.0409	258.14[b]	305.10[a]	4.87	<0.0001

[1]Total of all lean cuts (g/kg of total lean cut), includes: Loin, ham, butt and picnic.

Table 17. Interaction of the effects of flaxseed level and gender on the total of lean cuts (g/kg) of grower and finisher pigs

	Gilts			Barrows				
Flaxseed, %	0	5	10	0	5	10	SEM	P value
Total Lean	644.97	646.61	651.18	582.91	612.7	614.92	7.72	0.1341
Total Bone	95.34	94.05	93.44	88.92	92.12	93.21	1.77	0.1074
Total Subcutaneous Fat	202.32	207.14	204.77	256.06	235.16	228.87	7.35	0.0944
Total Body Cavity Fat	6.71	6.67	6.25	7.90	7.80	7.26	0.42	0.9646
Total Intramuscular Fat	50.65	45.53	44.37	64.20	52.15	55.74	2.04	0.1204
Total Dissectible Fat	259.69	259.34	255.38	328.16	295.27	291.87	8.44	0.0920

Table 18. Effect of different levels of flaxseed and gender on the C18:3n-3 and the n-6/n-3 ratio of inner and outer back fat of grower finisher pigs

	Flaxseed, %					Gender			
	0	5	10	SEM	P value	Gilts	Barrows	SEM	P value
Inner fat									
C18:3n-3	0.690[a]	5.670[b]	13.715[c]	0.145	<0.0001	6.735	6.649	0.119	0.610
n-6/n-3	8.254[a]	1.396[b]	0.751[c]	0.818	<0.0001	3.583	3.351	0.067	0.017
Outer fat									
C18:3n-3	1.008[a]	6.596[b]	15.213[c]	0.171	<0.0001	7.600	7.612	0.139	0.945
n-6/n-3	7.475[a]	1.459[b]	0.790[c]	0.515	<0.0001	3.290	3.193	0.418	0.103

Table 19. The effect of gender or 0, 5 or 10 % flaxseed in the diet on trained taste panel perceptions of palatability of fresh pork.

	Sex				Diet				
	Female	Male	SEM	P value	0	5	10	SEM	P value
Taste Panellist Mean Values									
Initial Tenderness	5.49	5.79	0.14	0.1524	5.96	5.49	5.47	0.18	0.0915
Initial Juiciness	5.76	5.82	0.12	0.6319	5.83	5.81	5.73	0.13	0.7536
Flavour Desirability	4.89	4.93	0.11	0.6368	5.14^{a}	4.84^{b}	4.75^{b}	0.12	**0.0019**
Pork Flavour Intensity	4.45^{b}	4.67^{a}	0.08	**0.0007**	4.79^{a}	4.47^{b}	4.40^{b}	0.09	**<0.0001**
Off Flavour Intensity	7.18	7.17	0.09	0.8924	7.39^{a}	7.16^{ab}	6.98^{b}	0.11	**0.0284**
Sustainable Juiciness	5.63	5.67	0.09	0.6872	5.70	5.67	5.57	0.10	0.5047
Overall Tenderness	5.87	6.12	0.12	0.1338	6.25	5.86	5.88	0.15	0.1126
Overall Palatability	4.44	4.59	0.10	0.1866	4.76^{a}	4.43^{b}	4.36^{b}	0.11	**0.0071**
Taste Panellist Standard Deviation									
Initial Tenderness	1.00	0.93	0.05	0.3420	0.88	0.95	1.07	0.06	0.1057
Initial Juiciness	0.96	0.95	0.06	0.8164	0.96	0.91	1.00	0.06	0.4830
Flavour Desirability	1.03^{b}	1.21^{a}	0.04	**0.0036**	1.17	1.15	1.04	0.05	0.1692
Pork Flavour Intensity	0.95^{b}	1.09^{a}	0.03	**0.0033**	1.05	1.04	0.96	0.04	0.1854
Off Flavour Intensity	1.48^{b}	1.68^{a}	0.07	**0.0272**	1.50	1.69	1.54	0.08	0.1825
Sustainable Juiciness	0.94	0.93	0.04	0.7027	0.94	0.97	0.89	0.04	0.4076
Overall Tenderness	1.27^{a}	1.08^{b}	0.05	**0.0099**	1.11	1.17	1.25	0.06	0.3173
Overall Palatability	1.04^{b}	1.21^{a}	0.04	**0.0071**	1.21^{a}	1.17^{a}	0.99^{b}	0.05	**0.0118**
Flavour Descriptor Percentages									
Metallic	2.01	1.65	0.81	0.7022	1.67	2.59	1.23	0.93	0.4776
Off sour	33.85^{a}	22.97^{b}	2.77	**0.0066**	32.59	27.92	24.72	3.39	0.2571
Barny	3.61	6.17	1.29	0.1626	3.29	5.52	5.86	1.58	0.4579
Stale	6.10	7.03	1.21	0.5892	4.91^{b}	5.19^{b}	9.60^{a}	1.49	**0.0476**
Rancid	0.89	1.22	0.65	0.6673	1.34	0.94	0.89	0.76	0.8736
Other	2.72^{b}	5.63^{a}	1.03	**0.0420**	2.40	4.77	5.36	1.25	0.1980
Unidentified	25.97	27.39	2.43	0.6787	23.88^{b}	22.67^{b}	33.48^{a}	2.97	**0.0220**
None	24.85	27.95	2.44	0.3723	29.91^{a}	30.43^{a}	18.86^{b}	2.99	**0.0106**
Texture Descriptor Percentages									
Typical Pork	68.79	66.13	3.06	0.3826	68.75	66.38	67.24	3.41	0.8123
Mushy	6.58	8.53	1.64	0.3887	7.59	7.56	7.53	1.99	0.9998
Mealy	11.87	13.56	2.03	0.4963	15.01	11.75	11.38	2.38	0.4223
Spongy	0.30	0.26	0.28	0.9261	0.39	0.00	0.45	0.35	0.6154
Rubbery	12.46	11.44	1.98	0.7153	8.26	14.20	13.39	2.43	0.1777
Cooking Data									
Cooktime, sec.g-1	6.36	6.76	0.24	0.1220	6.54	6.66	6.48	0.27	0.8394
Cookloss, mg.g-1	191.66	186.05	5.84	0.3524	189.38	189.79	187.39	6.56	0.9409
Marbling	3.1^{b}	3.9^{a}	0.12	<0.0001	3.7	3.5	3.3	0.15	0.1108

Table 20. The interaction of gender and 0, 5 or 10 % flaxseed in the diet on trained taste panel perceptions of palatability of fresh pork

	Female			Male				
	0	5	10	0	5	10	SEM	P value
Taste Panellist Mean Values								
Initial Tenderness	5.78	5.56	5.15	6.14	5.43	5.79	0.25	0.2944
Initial Juiciness	5.89	5.80	5.59	5.77	5.82	5.86	0.17	0.4095
Flavour Desirability	5.08	4.78	4.80	5.21	4.89	4.69	0.15	0.5209
Pork Flavour Intensity	4.68	4.36	4.30	4.90	4.59	4.50	0.10	0.9678
Off Flavour Intensity	7.31	7.15	7.09	7.47	7.17	6.87	0.15	0.4529
Sustainable Juiciness	5.76	5.67	5.46	5.64	5.68	5.68	0.13	0.3647
Overall Tenderness	6.12	5.86	5.62	6.64	5.86	6.13	0.20	0.4667
Overall Palatability	4.69	4.39	4.26	4.84	4.47	4.46	0.15	0.9134
Taste Panellist Standard Deviation								
Initial Tenderness	0.93	0.91	1.17	0.83	1.00	0.97	0.09	0.2830
Initial Juiciness	0.92	0.93	1.05	1.00	0.89	0.95	0.08	0.4318
Flavour Desirability	1.09	1.05	0.94	1.25	1.25	1.13	0.07	0.9682
Pork Flavour Intensity	1.07^{a}	0.90^{bc}	0.88^{c}	1.04^{ab}	1.18^{a}	1.04^{ab}	0.06	**0.0243**
Off Flavour Intensity	1.42	1.60	1.42	1.59	1.79	1.66	0.11	0.9400
Sustainable Juiciness	0.91	0.99	0.94	0.98	0.95	0.85	0.06	0.3838
Overall Tenderness	1.17	1.20	1.45	1.05	1.14	1.05	0.09	0.1403
Overall Palatability	1.15	1.10	0.86	1.27	1.23	1.12	0.08	0.5768
Flavour Descriptor Percentages								
Metallic	2.57	3.46	0.00	0.78	1.72	2.46	1.23	0.1048
Off sour	40.29	31.92	29.35	24.89	23.93	20.09	4.79	0.7106
Barny	2.57	4.02	4.24	4.02	7.02	7.48	2.23	0.9090
Stale	4.91	5.02	8.37	4.91	5.36	10.83	2.10	0.8173
Rancid	1.79	0.89	0.00	0.89	1.00	1.79	1.01	0.3569
Other	3.24^{b}	3.24^{b}	1.67^{b}	1.56^{b}	6.30^{ab}	9.04^{a}	1.75	**0.0361**
Unidentified	19.42	21.54	36.94	28.35	23.81	30.02	4.20	0.1692
None	25.22	29.91	19.42	34.60	30.95	18.30	4.23	0.4252
Texture Descriptor Percentages								
Typical Pork	71.65	68.19	66.52	65.85	64.57	67.97	4.30	0.6029
Mushy	7.48	5.69	6.58	7.70	9.42	8.48	2.78	0.8182
Mealy	11.83	12.72	11.05	18.19	10.78	11.72	3.20	0.3806
Spongy	0.00	0.00	0.89	0.78	0.00	0.00	0.49	0.2334
Rubbery	9.04	13.39	14.96	7.48	15.00	11.83	3.44	0.7841
Cooking Data								
Cooktime, sec.g-1	6.38	6.36	6.33	6.70	6.96	6.63	0.35	0.8711
Cookloss, mg.g-1	188.75	192.88	193.36	190.00	186.71	181.43	8.38	0.6662
Marbling	3.3	3.1	2.9	4.1	3.9	3.6	0.21	0.9053

Table 21. The effect of gender or 0, 5 or 10 % flaxseed in the diet on trained taste panel perceptions of palatability of a chop reheated 24 hr after initial cooking.

	Sex				Diet				
	Female	Male	SEM	P value	0	5	10	SEM	P value
Taste Panellist Mean Values									
Initial Tenderness	4.81[b]	5.31[a]	0.14	**0.0123**	5.30	5.12	4.75	0.17	0.0674
Initial Juiciness	4.00	4.15	0.10	0.2824	4.06	4.23	3.92	0.12	0.2060
Flavour Desirability	4.70	4.66	0.12	0.6086	4.94[a]	4.86[a]	4.23[b]	0.13	**<0.0001**
Pork Flavour Intensity	4.51	4.49	0.06	0.8538	4.71[a]	4.62[a]	4.17[b]	0.07	**<0.0001**
Off Flavour Intensity	6.82	6.67	0.17	0.1950	7.11[a]	6.93[a]	6.20[b]	0.18	**<0.0001**
Sustainable Juiciness	4.57	4.67	0.08	0.4175	4.62	4.69	4.56	0.10	0.6351
Overall Tenderness	5.16[b]	5.57[a]	0.12	**0.0152**	5.51	5.43	5.15	0.14	0.1686
Overall Palatability	3.76	3.90	0.09	0.1350	4.05[a]	3.97[a]	3.48[b]	0.10	**<0.0001**
Taste Panellist Standard Deviation									
Initial Tenderness	1.10	0.99	0.05	0.1376	1.08	0.95	1.10	0.06	0.1698
Initial Juiciness	1.07	1.10	0.04	0.5507	1.09	1.08	1.07	0.04	0.9415
Flavour Desirability	1.04	1.12	0.04	0.1561	1.01	1.10	1.13	0.05	0.1918
Pork Flavour Intensity	1.02	1.04	0.04	0.5815	0.97	1.05	1.07	0.04	0.2104
Off Flavour Intensity	1.59	1.60	0.08	0.8869	1.53	1.56	1.70	0.09	0.2113
Sustainable Juiciness	0.97	0.98	0.04	0.9129	0.98	0.92	1.03	0.04	0.2039
Overall Tenderness	1.37	1.34	0.05	0.6647	1.30	1.34	1.42	0.06	0.3344
Overall Palatability	0.93	0.99	0.06	0.3156	1.04	0.99	0.84	0.07	0.0306
Flavour Descriptor Percentages									
Metallic	0.00	0.56	0.27	0.1522	0.00	0.00	0.84	0.33	0.1289
Off sour	15.81	13.61	1.76	0.3786	17.80[a]	16.68[a]	9.65[b]	2.15	**0.0174**
Barny	1.60	4.43	1.11	0.0539	2.46	3.75	2.85	1.33	0.7601
Stale	26.19	22.71	2.24	0.2755	24.89	24.14	24.33	2.74	0.9800
Rancid	2.75	4.45	1.38	0.1330	1.34[b]	1.59[b]	7.87[a]	1.49	**<0.0001**
Other	5.77[b]	10.38[a]	1.82	**0.0139**	1.17[b]	4.19[b]	18.86[a]	2.04	**<0.0001**
Unidentified	28.91	25.42	2.15	0.2550	28.46	27.48	25.56	2.63	0.7286
None	18.97	18.33	2.26	0.8224	23.88[a]	22.02[a]	10.04[b]	2.68	**0.0002**
Texture Descriptor Percentages									
Typical Pork	48.70	52.97	2.37	0.2044	52.23	50.44	49.83	2.90	0.8293
Mushy	2.19	3.15	0.95	0.4274	0.89[b]	5.06[a]	2.06[b]	1.12	**0.0171**
Mealy	27.01	27.99	3.47	0.8103	31.03	26.64	24.83	4.02	0.4415
Spongy	0.00	0.00	0.00	1.0000	0.00	0.00	0.00	0.00	1.0000
Rubbery	22.10	15.95	2.22	0.0531	15.85	17.96	23.27	2.71	0.1408
Cooking Data									
Initial Cooktime, sec.g-1	6.03[b]	6.58[a]	0.19	**0.0268**	6.11	6.48	6.32	0.22	0.4606
Initial Cookloss, mg.g-1	195.67	194.82	5.28	0.8762	192.06	194.36	199.31	5.93	0.5350
Reheat Cooktime, sec.g-1	8.55[b]	9.36[a]	0.24	**0.0170**	8.88	8.87	9.11	0.29	0.8067
Reheat Cookloss, mg.g-1	83.17	85.46	2.44	0.5086	86.91	79.66	86.36	2.99	0.1699
Marbling	3.3[b]	3.9[a]	0.15	**0.0043**	3.8	3.7	3.5	0.19	0.4224

Table 22. The interaction of gender and 0, 5 or 10 % flaxseed in the diet on trained taste panel perceptions of palatability of a chop reheated 24 hr after initial cooking

	Female			Male				
	5	5	10			10	SEM	Prob
Taste Panellist Mean Values								
Initial Tenderness	5.03	5.10	4.30	5.58	5.14	5.21	0.24	0.2006
Initial Juiciness	4.04	4.13	3.82	4.09	4.32	4.03	0.17	0.8763
Flavour Desirability	4.87[a]	4.84[a]	4.40[b]	5.02[a]	4.89[a]	4.06[c]	0.15	**0.0453**
Pork Flavour Intensity	4.64	4.62	4.26	4.78	4.61	4.09	0.10	0.2776
Off Flavour Intensity	7.02[a]	6.95[a]	6.50[b]	7.20[a]	6.91[ab]	5.89[c]	0.21	**0.0234**
Sustainable Juiciness	4.62	4.60	4.51	4.62	4.78	4.61	0.14	0.7983
Overall Tenderness	5.34	5.32	4.81	5.69	5.54	5.48	0.20	0.5227
Overall Palatability	3.97	3.88	3.45	4.13	4.07	3.51	0.13	0.8430
Taste Panellist Standard Deviation								
Initial Tenderness	1.11	0.97	1.21	1.05	0.94	0.99	0.08	0.4702
Initial Juiciness	1.07	1.09	1.04	1.12	1.07	1.10	0.06	0.7973
Flavour Desirability	0.97	1.08	1.08	1.06	1.12	1.18	0.07	0.9144
Pork Flavour Intensity	0.96	1.04	1.05	0.98	1.05	1.09	0.06	0.9520
Off Flavour Intensity	1.51	1.59	1.67	1.55	1.53	1.72	0.11	0.8301
Sustainable Juiciness	0.99	0.84	1.08	0.96	1.00	0.97	0.06	0.0890
Overall Tenderness	1.30	1.36	1.46	1.30	1.33	1.39	0.09	0.9413
Overall Palatability	1.02	0.99	0.77	1.05	0.99	0.92	0.09	0.6196
Flavour Descriptor Percentages								
Metallic	0.00	0.00	0.00	0.00	0.00	1.67	0.47	0.1289
Off sour	19.87	17.52	10.04	15.74	15.83	9.26	3.04	0.8496
Barny	0.89	3.13	0.78	4.02	4.37	4.91	1.83	0.7138
Stale	26.79	24.11	27.68	22.99	24.17	20.98	3.88	0.6859
Rancid	0.89	1.56	5.80	1.76	1.62	9.93	1.77	0.2954
Other	0.78[c]	3.35[c]	13.17[b]	1.56[c]	5.03[c]	24.55[a]	2.59	**0.0368**
Unidentified	30.69	27.46	28.57	26.23	27.50	22.54	3.72	0.7020
None	20.09	22.88	13.95	27.68	21.16	6.14	3.65	0.0921
Texture Descriptor Percentages								
Typical Pork	51.45	49.22	45.42	53.01	51.66	54.24	4.10	0.6258
Mushy	0.89	4.80	0.89	0.89	5.31	3.24	1.53	0.7004
Mealy	30.25	27.68	23.10	31.81	25.60	26.56	5.35	0.8539
Spongy	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.0000
Rubbery	17.41	18.30	30.58	14.29	17.62	15.96	3.84	0.1581
Cooking Data								
Initial Cooktime, sec.g-1	5.93	6.17	5.98	6.28	6.80	6.67	0.31	0.8345
Initial Cookloss, mg.g-1	191.01	196.94	199.05	193.11	191.78	199.58	7.56	0.8494
Reheat Cooktime, sec.g-1	8.51	8.56	8.57	9.26	9.17	9.64	0.41	0.8539

Reheat Cookloss, mg.g-1	85.78	78.25	85.47	88.04	81.07	87.25	4.22	0.9925
Marbling	3.5	3.1	3.4	4.1	4.2	3.5	0.25	0.1990

Table 23. The interaction of gender and 0, 5 or 10 % flaxseed in the diet on trained taste panel perceptions of palatability of a chop reheated 24 hr after initial cooking

	Sex				Diet				
	Female	Male	SEM	P value	0	5	10	SEM	P value
Taste Panellist Mean Values									
Initial Tenderness	8.01	7.98	0.03	0.2591	7.91^{c}	8.00^{b}	8.07^{a}	0.03	**0.0001**
Initial Juiciness	5.46	5.48	0.09	0.8251	5.28^{b}	5.58^{a}	5.55^{a}	0.11	**0.0310**
Flavour Desirability	4.72	4.63	0.08	0.2463	5.18^{a}	4.86^{b}	4.00^{c}	0.08	**<0.0001**
Pork Flavour Intensity	4.23	4.18	0.07	0.4891	4.69^{a}	4.28^{b}	3.65^{c}	0.08	**<0.0001**
Off Flavour Intensity	6.75	6.55	0.09	0.0727	7.47^{a}	6.81^{b}	5.66^{c}	0.11	**<0.0001**
Sustainable Juiciness	5.82	5.85	0.09	0.7881	5.62^{b}	5.94^{a}	5.94^{a}	0.09	**0.0006**
Overall Tenderness	8.01	8.01	0.07	0.9085	7.88^{b}	8.05^{a}	8.09^{a}	0.07	**<0.0001**
Overall Palatability	4.36^{a}	4.19^{b}	0.08	**0.0474**	4.74^{a}	4.45^{b}	3.62^{c}	0.09	**<0.0001**
Taste Panellist Standard Deviation									
Initial Tenderness	0.62	0.62	0.02	0.9242	0.64^{a}	0.65^{a}	0.58^{b}	0.02	**0.0427**
Initial Juiciness	1.04	1.12	0.07	0.1343	1.09	1.04	1.10	0.08	0.6537
Flavour Desirability	1.14	1.17	0.05	0.5915	1.20	1.16	1.11	0.06	0.3319
Pork Flavour Intensity	1.21	1.17	0.06	0.3380	1.29^{a}	1.20^{a}	1.07^{b}	0.07	**0.0002**
Off Flavour Intensity	1.62	1.70	0.08	0.3110	1.53^{b}	1.69^{ab}	1.77^{a}	0.09	**0.0473**
Sustainable Juiciness	1.07	1.16	0.08	0.1139	1.09	1.10	1.16	0.08	0.6331
Overall Tenderness	0.58	0.59	0.03	0.7763	0.60	0.58	0.58	0.04	0.8621
Overall Palatability	1.22	1.22	0.07	0.9519	1.35^{a}	1.23^{ab}	1.08^{b}	0.07	**0.0025**
Flavour Descriptor Percentages									
Metallic	0.00	0.37	0.25	0.2933	0.00	0.56	0.00	0.30	0.3355
Off sour	14.97^{a}	9.77^{b}	2.84	**0.0470**	19.68^{a}	10.70^{b}	6.73^{b}	3.11	**0.0003**
Barny	4.64	4.89	1.16	0.8783	5.79	4.58	3.92	1.41	0.6338
Stale	11.45	12.28	1.41	0.6596	12.48	14.03	9.08	1.70	0.0968
Rancid	11.16^{b}	15.52^{a}	2.10	**0.0476**	5.79^{b}	8.97^{b}	25.26^{a}	2.37	**<0.0001**
Other	25.32	24.35	1.89	0.7160	7.12^{c}	28.64^{b}	38.75^{a}	2.31	**<0.0001**
Unidentified	12.69	14.39	1.58	0.4478	16.02	11.50	13.10	1.94	0.2530
None	19.78	18.43	1.83	0.6027	33.13^{a}	21.02^{b}	3.16^{c}	2.24	**<0.0001**
Texture Descriptor Percentages									
Typical Pork	14.62	17.16	2.97	0.2829	24.27^{a}	13.32^{b}	10.08^{b}	3.19	**<0.0001**
Mushy	33.11	29.64	2.60	0.3476	11.94^{c}	36.10^{b}	46.08^{a}	3.19	**<0.0001**
Mealy	52.27	53.16	3.73	0.7703	63.78^{a}	50.52^{b}	43.84^{b}	4.03	**<0.0001**
Spongy	0.00	0.00	0.00	1.0000	0.00	0.00	0.00	0.00	1.0000
Rubbery	0.00	0.00	0.00	1.0000	0.00	0.00	0.00	0.00	1.0000
Cooking Data									
Cookloss, mg.g-1	236.66^{b}	247.03^{a}	3.67	**0.0393**	254.06^{a}	232.95^{b}	238.08^{b}	4.47	**0.0030**

Table 24. The interaction of gender and 0, 5 or 10 % flaxseed in the diet on trained taste panel perceptions of palatability of a chop reheated 24 hr after initial cooking

	Female			Male				
	0	5	10	0	5	10	SEM	Prob
Taste Panellist Mean Values								
Initial Tenderness	7.97	8.02	8.05	7.86	7.98	8.10	0.04	0.0874
Initial Juiciness	5.40	5.55	5.44	5.17	5.62	5.67	0.14	0.1646
Flavour Desirability	5.19	4.98	4.00	5.17	4.73	4.00	0.11	0.3678
Pork Flavour Intensity	4.63	4.33	3.73	4.74	4.22	3.58	0.10	0.2530
Off Flavour Intensity	7.58	7.02	5.65	7.37	6.61	5.66	0.14	0.3049
Sustainable Juiciness	5.71	5.87	5.90	5.53	6.02	5.98	0.11	0.1922
Overall Tenderness	7.93	8.02	8.08	7.84	8.09	8.09	0.07	0.0936
Overall Palatability	4.79	4.59	3.68	4.69	4.31	3.56	0.12	0.6359
Taste Panellist Standard Deviation								
Initial Tenderness	0.65	0.66	0.56	0.63	0.64	0.60	0.03	0.5535
Initial Juiciness	0.99	1.03	1.09	1.20	1.05	1.12	0.09	0.2906
Flavour Desirability	1.08^{b}	1.24^{ab}	1.10^{b}	1.33^{a}	1.08^{b}	1.11^{b}	0.07	**0.0098**
Pork Flavour Intensity	1.29	1.23	1.10	1.29	1.18	1.03	0.08	0.7678
Off Flavour Intensity	1.46	1.68	1.73	1.61	1.70	1.80	0.11	0.8201
Sustainable Juiciness	1.03	1.03	1.14	1.15	1.17	1.17	0.10	0.7535
Overall Tenderness	0.57	0.61	0.56	0.63	0.55	0.60	0.05	0.2838
Overall Palatability	1.31	1.29	1.06	1.40	1.17	1.11	0.09	0.3553
Flavour Descriptor Percentages								
Metallic	0.00	0.00	0.00	0.00	1.11	0.00	0.43	0.3355
Off sour	22.14	11.87	10.90	17.22	9.53	2.57	3.83	0.6378
Barny	8.00	2.57	3.35	3.57	6.59	4.50	1.99	0.1020
Stale	9.90	14.81	9.64	15.07	13.25	8.52	2.36	0.2698
Rancid	3.61	8.52	21.35	7.96	9.42	29.17	3.02	0.4346
Other	7.85	25.45	42.67	6.40	31.83	34.82	3.27	0.1001
Unidentified	14.69	12.05	11.31	17.34	10.95	14.88	2.74	0.6688
None	33.82	24.74	0.78	32.44	17.30	5.54	3.17	0.1641

Texture Descriptor Percentages								
Typical Pork	22.28	13.50	8.07	26.26	13.14	12.09	3.79	0.6866
Mushy	16.56	39.58	43.19	7.33	32.62	48.96	4.51	0.2035
Mealy	61.16[ab]	46.91[cd]	48.74[cd]	66.41[a]	54.13bc	38.95[d]	4.81	**0.0496**
Spongy	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.0000
Rubbery	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.0000
Cooking Data								
Cookloss, mg.g-1	241.70	230.07	237.32	266.41	235.83	238.85	6.28	0.1455

REFERENCES

Gatlin, L.A., M.T. See, J.A. Hansen, L. Sutton and J Odle. 2002. The effects of dietary fat sources, levels and feeding intervals on pork fatty acid composition. J.Anim. Sci. 80:1606-1615.

Grossu D, Iliescu MandMoisa A. 1998. Nutritive value of full-fat flax seed used in broiler chickens feeding. *Biol Landwirtsch Nutz* 11:34–35.

Htoo, J. K., X. Meng, J. F. Patience and R. T. Zijlstra. 2007. Energy digestibility and DE content of co-extruded flax and pea for grower pigs. J. Anim. Sci., 85(Suppl. 2): 109.

Romans, J.R., R.C. Johnson, D.M. Wulf, G.W. Libal and W.J. Costello. 1995. Effects of ground flaxseed in swine diets on pig performance and on physical and sensory characteristics and omega-3 fatty acid content of pork: 1. Dietary level of flaxseed. J.Anim. Sci. 73:1982-1986.

Thacker, P. A., V. J. Racz, and H. W. Soita. 2004. Performance and carcass characteristics of growing-finishing pigs fed barley-based diets supplemented with Linpro (extruded whole flaxseed and peas) or soybean meal. Can. J. Anim. Sci. 84:681–688.

Impact of feeding diets containing extruded flaxseed meal and vitamin E in finishing swine

A.D. Beaulieu[1], M.E.R. Dugan[2], J. L. Aalhus[2] and R.T. Zijlstra[3]

[1]Prairie Swine Centre, Inc., Saskatoon, SK.
[2]Lacombe Research Centre, Agriculture and Agri-Food Canada, Lacombe AB.
[3]University of Alberta, Edmonton, AB.

Justification

The project will support directly or indirectly many areas of agricultural development by increasing livestock development, crop production, improving food quality and expanding processing.

The use of extruded flaxseed meal in the swine diet will provide an opportunity to the pork producers to create a line of pork branded as "omega –3 pork" in the market place. This value added product in the market will fetch a higher price and will provide higher returns to the pig producers. It will not only expand the market but will also contribute to the overall pig production.

Previous experiments in this series indicated that 5 % extruded flaxseed in the diet (10% LinPro) for 11 weeks enriched some cuts of pork sufficiently to allow a claim of "omega-3 enriched" (300 mg omega-3 per 100 grams). At the high levels of enrichment there was some indications of off-flavours by the taste panels. The objective of this experiment is to determine if additional vitamin E[2] would have an effect on these off-flavours.

Hypothesis

Supplemental extruded flaxseed meal fed for extended period of time will result in an omega-e enriched pork, and if fed with additional vitamin E the pork will not exhibit any indications of rancidity.

Objective

To study the impact of feeding vitamin E in conjunction with extruded flaxseed on the incidence of rancidity in omega-3 enriched pork products.

Materials and Methods

Experimental Design

The experiment was conducted according to a completely randomized design having a 3 x 2 x 2 factorial arrangement of treatments (Table 1). Treatments were three diets (1) Control, 2) 5 % extruded flaxseed and 3) 5 % extruded flaxseed plus 200 mg/kg diet vitamin E.), 2 genders and 2 initial/final weight group treatments . The pigs were assigned to diet in 4 blocks of 24, at intervals of 1 week. Each block consisted of 12 pigs from each initial weight group, (6 barrows and 6 gilts). The vitamin E treatment was formulated to contain 200 mg/kg vitamin E which is equivalent to 200 IU/kg dl-α tocopherol acetate.

Diets

Diets were based on wheat, barley and soybean meal (Table 2). They were fed in 3 phases, formulated to meet or exceed nutrient requirements for animals at each stage of growth. Diet change was according to weight, within phase and gender, thus, depending on starting weight, the pigs were on each diet for varying amounts of time.

The flaxseed was added as Linpro® (O & T Farms, Regina, SK), an extruded (50:50) pea/flaxseed blend using extrusion conditions (single screw, 500 psi, no added water, barrel temperature of 135 °C) optimized in a previous experiment (Htoo et al. 2008). Field peas were added to the diets to compensate for the peas added in the Linpro. The vitamin E was added to a premix prior to mixing with the main ingredients. The vitamin E used was Rovimix E-50 Adsorbate, manufactured by DSM (Netherlands). The premix contains > 50 % activity dl α tocopherol acetate (therefore a minimum of 1 IU dl-α tocopherol acetate per 2 mg of premix).

---

[2]Growing pigs from 10 to 120 kg BW require 11 IU/kg Vitamin E (NRC 1998). 1 IU Vit E = 0.67 mg of D-α-tocopherol or 1 mg of DL-α-tocopheryl acetate.

A special premix without any added vitamin E was prepared for this experiment. Rovimix E-50 was added to the control and the 5 % flaxseed diets at 0.0022 % which supplies 11 mg/kg diet, meeting the vitamin E requirement for pigs of this age (NRC 1998), but not supplying any excess or "safety margin".

Supplemental selenium was added to the Phase 3 diets, when it was discovered that the mineral premix did not contain selenium. The selenium premix supplied 200 mg Se/kg and therefore at the add rate of 0.075 % supplied 0.15 mg/kg which meets the requirement for pigs of this age according to NRC 1998.

Diets were fed as a mash. Feed and water were freely available.

Animal Selection and Care

All animals used in this study were raised and slaughtered in accordance with the principals and guidelines established by the Canadian Council on Animal Care (1993). The experiment was conducted using 96 pigs (48 gilts and 48 barrows). Each week 24 animals were selected based to meet the required body weight and gender requirements. Because of the initial body weight requirement, (30 ± 4 or 44 ± kg) they were selected from two different farrowing groups. Within each gender and weight group pigs were randomly assigned to treatment. Treatments were randomly assigned to pens within a 24 pen block.

Pigs were housed in individual pens (0.91 x 1.83m). Flooring was concrete, fully slatted. The penning was solid precast walls with a 7.5 cm opening at the back wall to allow pig to pig contact. Front gates and pen sides are PVC planking. Each pen has a water nipple located on the centre back wall, adjusted to shoulder height as the pig grew, and a single feeder at the front of the feeder. Lights were on a 14 h (0700 to 2100) light followed by a 10 h dark period. Three blocks were conducted in one room, and one block in an identical, adjoining room.

Body weights of the pigs were recorded every two weeks. Feed refusals were also weighed on these days to allow calculation of ADG, ADF and feed efficiency. At the completion of a 12 week feeding period, feed was removed at 1130 AM, the pigs were loaded into a trailer and shipped to Lacombe, AB, scheduled to arrive at approximately 1830 that day. Animals were fasted overnight and slaughtered the following day. Feed samples were submitted to Central Testing Laboratory, Ltd. (Winnipeg, MB) for analysis of moisture, crude protein, ether extract, Ca, P, Mg, K and Na. A subset of samples were analyzed for Se and Vit E.

Slaughter

Animals were shipped to Lacombe Research Centre for slaughter over the course of 4 weeks (23, 22, 23 and 24 animals respectively as a few animals died in transit or prior to shipment). Animals arrived mid-afternoon the day prior to slaughter and were held over night until slaughter. At time of slaughter final live weights were recorded and animals were stunned, exsanquinated and dressed in a simulated commercial manner. During the course of dressing, weights were recorded for the kidneys, leaf lard, front feet and head. Following splitting of the carcass, hot side weights were recorded. At 45-minutes postmortem an estimated lean yield was determined on the left side between the 3rd and 4th anterior rib approximately 7 cm from the midline (Anitech PG100 Grading Probe [Anitech Information Systems Inc., Markham ON]). A 45-minute pH and temperature was recorded on the left *longissimus thorasis lumborum* (LTL) between the 11th and 12th vertebrae (Hannah HI9025C pH meter [Hannah Instruments, Mississauga ON] equipped with an Orion Ingold electrode [Udorf, Switzerland]).

Carcass Dissection

At 24 hours, left and right carcass sides were weighed to determine cooler shrink loss. The left side of the carcass was then broken down into primals (picnic, butt, hock, ham, loin, and belly) and subsequently dissected into lean, bone and subcutaneous, intermuscular and body cavity fat as described by Martin et al (1981). One animal from each diet and gender from both the light (107 kg) and heavy (117 kg) target weights was selected for further fatty acid and proximate analysis determinations on the loin and ham (n=12). The loin from those animals selected for further analysis was taken down to ¼ inch subcutaneous fat. This ¼ inch was then removed, weighed (weight recorded back into total subcutaneous fat for dissection data) and blixed (Robot

Coupe Blixir BX3 [Robot Coupe USA Inc., Ridgeland MS]). The blixed sample was then pre-weighed into vials for further fatty acid analysis. The intermuscular fat from these primals was also blixed as described above and sub-sampled for fatty acid analysis. The lean from the loin and ham from was ground three times (Butcher Boy Meat Grinder Model TCA22 with a 1/8-inch grind plate [Lasar Manufacturing Co., Los Angeles, CA]). A 100g sub-sample was weighed into stainless steel beakers and placed in a gravity convection-drying oven at 102°C for a 24-hour period (VWR Scientific Model 1370FM [Mississauga, ON]). Beakers were removed from the oven and final weights recorded for moisture loss determination. The dried sample was pulverized to a fine grind (Grindomix Model GM200 [Retsch Inc., Newton, PA]) and analyzed for crude fat content (Method 960.39; Association of Official Analytical Chemists 1995) by petroleum ether extraction (Foss Soxtec System Model 2050 [Foss Analytical AB, Hoganas, Sweden]). Nitrogen content (Method 992.15; Association of Official Analytical Chemists 1995) was determined from fat free grind (Nitrogen/Protein Determinator CNS2000, [Leco Corp., St. Joseph, MI]) to complete proximate analysis. Approximately 100g of the original 3x grind was blixed using the robot coupe and sub-sampled as previously described for fatty acid determinations. During the course of carcass dissection rib-eyes (bone-in) were photographed and image analysis used to determine marbling scores. As well the softness of skin-on bellies was determined by draping them, skin down, over a rod, 8.3 cm in diameter, for a 2 minute period and then measuring the distance between the two hanging ends (Murray and Johns 2003).

Meat Quality

Meat quality analysis including fat hardness readings (0 to 100 durometer units) were determined on the right sides of the carcasses at the 1st and 2nd thoracic vertebrae on the second subcutaneous fat layer (Rex Durometer LG2400 [Rex Gauge Company, Buffalo Grove, IL]) in accordance with specification standard ASTM D-2240. The right LTL was removed, labelled and taken down to ¼ inch subcutaneous fat. The remaining ¼ inch fat was removed, labeled, polybagged and stored in a cooler at 2°C with wind speeds of 0.5m/sec until 48 hours postmortem. The trimmed LTL was cut into the LT and LL portions at the grade site and labeled accordingly. The LL was polybagged and stored in cooler with subcutaneous fat samples until 48 hours for sensory evaluation. A 25 mm chop removed from the posterior end of the LT was pre-weighed into a polystyrene tray with a dri-loc pad, over-wrapped with oxygen permeable film (8000 ml m^{-2} 24 h^{-1} vitafilm choice wrap [Goodyear Canada Inc.]) and stored at 2°C for 2 days to determine drip loss. The remainder of the muscle was polybagged and stored in a cooler until remaining quality determinations at 48 hours.

At 48 hours, the LT muscles were removed from the cooler and pH and temperature readings collected from the posterior end. Muscles were trimmed of all extraneous fat and connective tissue. Following trimming, subjective colour and structure were evaluated as a consensus of three experienced raters using the Agriculture Canada Pork Quality Standards (Agriculture Canada, 1984). Colour and structure standard scores ranged from 1=extremely pale, soft, exudative with an open grainy texture to 5=extremely dark, firm, dry with a closed grainy texture. Following scoring a chop (25 mm) was removed and flash frozen in liquid nitrogen for vitamin E analysis protocol development. The remaining portion of the LT was then ground three times (FM/OMCAN Grinder Model FTS12 with a 1/8-inch grind plate [Staffers Supply Co., Langley, BC]). 100 g of the grind was dried to determine moisture loss and subsequent fat and protein to complete proximate analysis as described previously with all remaining grind being blixed in robot coupe and then sub-sampled for fatty acid determinations as well as for vitamin E development.

Four chops (25 mm) were removed from the LL samples. The first chop was allowed a 20-minute bloom period after which two objective color measurements (CIE L*[brightness], a*[red-green axis], b*[yellow-blue axis] values; [Commission Internationale de l'Eclairage, 1978]) were collected and converted to hue (H_{ab}=arctan[b*/a*]) and chroma (C_{ab}=$[a^{*2}+b^{*2}]^{0.5}$) (Minolta CR-300 with Spectra QC-300 Software [Minolta Canada Inc., Mississauga, ON]). Raw weights were collected on both the first and second chops prior to cooking. A spear point temperature probe (10 cm) was inserted into the mid-point of each chop. It was then grilled (Garland Grill ED30B [Condon Barr Food Equipment Ltd., Edmonton, AB]) to an internal temperature of 34°C, turned and cooked to a final temperature of 68°C (Hewlett Packard HP34970A Data Logger [Hewlett

Packard Co., Boise ID]). Total cooking time was recorded upon removal from the grill. Chops were placed into polyethylene bags, sealed and immediately immersed in an ice/water bath to prevent further cooking. They were then transferred to a cooler to allow standing for a 24-hour period. Final chop weight was recorded the following day and two cores per chop, 1.9 cm in diameter, were removed parallel to the fiber grain and peak shear force determined on each core perpendicular to the fiber grain (TA-XT Plus Texture Analyzer equipped with a Warner-Bratzler shear head at a crosshead speed of 200 mm/min. and a 30 kg load cell using Texture Exponent 32 Software [Texture Technologies Corp., Hamilton, MA]). Raw and final chop weights were used to determine cooking loss and cooking time expressed as the average of the two chops. Peak shear force was also expressed as the average of the 2 chops.

The third and fourth chops were labeled, vacuum packaged (Multivac AGW [Multivac Inc., Kansas City, MO]) and stored at -35°C for subsequent sensory analysis. The remainder of the muscle was trimmed of all extraneous fat and connective tissue. The ¼ inch subcutaneous fat previously removed from the LTL along with the remaining portion of the trimmed LL were cut and weighed to yield a 20% fat to lean ratio. The weighed LL and fat were then ground two times using the Butcher Boy meat grinder. 100g of the grind was dried to determine moisture, fat and protein content for proximate analysis while another 100g sub-sample was blixed with robot coupe for fatty acid determinations. The remaining grind was used to form a 140g patty (4 ½ inches diameter x ¼ inch thick) using a single patty hamburger press (Cabelas, Sydney, NE). Patties were labeled, and stored at -35°C for subsequent sensory analysis.

Sensory Evaluations

Paired taste panel chops were removed from the freezer and placed in a refrigerator to thaw for 24 hours. 15 minutes prior to grilling, the chops were removed from the refrigerator and raw weight recorded. Temperature probes were inserted horizontally to the mid-point along the long axis of the chop. Chops were grilled to an internal temperature of 34°C, turned and cooked to a final temperature of 68°C. After cooling for 3 minutes, final cooked weight was recorded for determination of cooking losses. One chop was cut into 1.3 cm cubes, avoiding connective tissue and large areas of fat. Eight cubes from each sample were randomly assigned to an eight-member trained taste panel to assess as a fresh frozen loin chop. Samples were placed in glass jars in a circulating water bath (Lindberg/Blue model WB1120A-1) and allowed to equilibrate to 68°C prior to evaluation. Attribute ratings were electronically collected using the Compusense 5, release 4.6 computer software using nine point descriptive scales for initial and overall tenderness (9=extremely tender; 1=extremely tough), initial and sustained juiciness (9=extremely juicy; 1=extremely dry), pork flavour intensity (9=extremely intense pork flavour; 1=extremely bland pork flavour) and off flavor intensity (9=extremely bland; 1= extremely intense). Flavour desirability and overall palatability were rated on a nine point hedonic scale, (9=extremely desirable; 1=extremely undesirable). Initial tenderness was rated on the first bite through the cut center surface with the incisors; initial juiciness was rated after 3-5 chews with the molars; pork flavour and flavour desirability between 10-20 chews and sustained juiciness, overall tenderness and over palatability rated prior to expelling. Each panellist also assigned one of the following flavour (metallic, off sour, barny, stale, rancid, other, unidentified or none) and texture (typical pork, mushy, mealy, spongy or rubbery) descriptors to each cube. Flavour and texture descriptors were reported as the percentage of panellists attributing that descriptor to that sample. All panel evaluations were conducted in well-ventilated, partitioned booths, under 180 lux green light. Distilled water and unsalted soda crackers were provided to purge the palate of residual flavour notes between samples (Larmond 1977). The remaining chop was poly-bagged and refrigerated for a 24 hour period. The following day the chop was removed from the refrigerator, reweighed prior to reheating, probes inserted and placed on grill to be reheated. Chops were flipped at 32°C and reheating continued to a final temperature of 65°C. Chop was removed from grill and final weight again recorded to determine reheating cooking losses. Chop was cut into 8 cubes and presented to panelists to assess as a fresh, frozen warmed over loin chop in same manner as described above. Hamburger patties were removed from freezer and thawed overnight in refrigerator. Raw weight was recorded prior to placing patty into non greased omelet pan (Jole Omelet Ease) preheated for 10 minutes on grill set to 205°C. Pans were placed on grill and cooked on one side for 4 minutes, flipped and cooked for an additional 8 minutes. Hamburger patty was

removed from omelet pan and cooled for 2 minutes prior to recording final cooked weight for determination of cook losses. Patty was then cut into 8 pie shaped pieces to be presented to taste panelists in same manner as described for fresh frozen and fresh frozen warmed over chops.

Statistical Analysis

Data was analyzed using the Mixed Model computer algorithm of the SAS Insititute, Inc. (2001) using the following models:

$\gamma = \mu$ + Gender + Diet with kill as a blocking effect.

where Diet is flax (5%), flax plus vitamin E (5% flax and 200 mg/kg vitamin E) and control (no flax or vitamin E).

Results

Main effects of treatment and gender on growth performance and feed intake are described in Table 4, while the effect of initial body weight is shown in Table 5. The statistical model contained the effects of treatment, gender and initial body weight and all interactions. The only two interactions which were significant ($P < 0.05$) are shown in Table 6. The inclusion of 5 % flaxseed in the diet, as an extruded flaxseed: pea mixture had no effect on average daily gain, feed intake or feed efficiency ($P > 0.05$). The ADG of males was greater than females overall, and specifically in phase 2 ($P < 0.0001$). Overall ADFI was greater in males and in each of the 3 phases ($P < 0.05$). Feed efficiency was slightly improved in males in each of the 3 phases ($P > 0.05$) and overall this improvement did reach statistical significance. There was a diet by gender interaction for feed intake (Table 6); this is apparently due to a different pattern of feed intake among the treatments in males versus females.

The pigs in the "heavy" weight group were 1 kg lighter than desired according to the experimental protocol, there still was an 8 kg difference between the heavy and light weight groups (Table 5; $P < 0.0001$). There were only modest effects of initial body weight on growth performance. ADG was improved in the heavy pigs in phase 1 ($P = 0.08$) and phase 2 ($P = 0.01$) but not in phase 3 ($P = 0.24$). There was an interaction of initial body weight and treatment on overall ADF ($P < 0.02$). The lowest ADF was observed with the flaxseed pigs in the heavy pigs, while in the light pigs, the highest feed intake was observed in this group.

The inclusion of 5 % flaxseed in the diet, with or without vitamin E, had no effect on cooler loss, hot weight, or dressing %, WHE equation, estimated lean yield, or marbling (Table 7a; $P > 0.05$). Fat hardness was decreased when the pigs were fed diets with 5 % added flaxseed regardless of the vitamin E content of the diet ($P < 0.001$). Plant weight and hot weight of the male pigs was heavier ($P < 0.02$); male pigs had more marbling and the fat was harder ($P < 0.04$). Female pigs had greater lean yield and estimated lean yield ($P < 0.0001$). There were no interactions of treatment and gender on any of the measured carcass parameters (Table 7b; $P > 0.05$).

Treatment had no effect on pH or temperature measured at either 45 minutes or 48 hours (Table 8a; $P > 0.05$). Similarly treatment did not effect meat color, whether measured subjectively or objectively, cook loss, cook time or drip loss ($P > 0.05$). Content of moisture, fat and protein in the lean, or with 20 % fat inclusion, was similar among treatments ($P > 0.05$).

Cook loss was greater in meat from male than female carcasses ($P < 0.03$) and the percentage of fat was higher ($P < 0.03$). The moisture content in the meat from female carcasses was higher than males ($P < 0.01$). The only treatment by gender interaction for meat quality parameters was for Hue ($P < 01$). In female pigs, the vitamin E treatment resulted in a reduced hue, indicating a darker red colour. This was not observed in the meat from the male pigs.

The effect of treatment or gender on proximate analysis of the ham and loin is shown in Table 9a. Treatment had no effect on moisture or protein content of the ham or loin or fat content of the ham ($P > 0.10$). The fat content of the loin increased from 4.5 % to 5.1 % with the inclusion of 5 % flaxseed in the diet regardless of the vitamin E content of the diet ($P < 0.03$). Moisture, fat and protein content of the ham were

similar between sexes ($P > 0.20$). Fat content was greater, and moisture and protein content reduced in the loins obtained from male pigs compared to females ($P < 0.01$). There were no interactions of treatment by sex on the moisture, fat or protein content of the hams or loins ($P > 0.05$).

Dietary treatment had no effect on the weight of the picnic, hock, butt, ham, loin or belly (Table 10a; $P > 0.10$). Female pigs had heavier hocks and hams ($P < 0.05$) regardless of dietary treatment (sex by treatment; $P > 0.10$). There was an interaction of treatment by sex for the weight of the belly. The belly weight of male pigs receiving 5 % flaxseed in their diets without supplemental vitamin E was reduced, an effect not observed in the female pigs (Table 10b; treatment by sex; $P < 0.05$).

Table 11a describes the effect of treatment or sex on the composition (lean, bone, subcutaneous fat, body cavity fat, or intermuscular fat) of individual primal cuts. A decrease in subcutaneous fat in the picnic was observed with 5 % added flaxseed in the diet ($P < 0.05$) and an intermediate value when vitamin E was also included in the diet. There were no other effects of treatment diet on the composition of the picnic, hock, ham, loin, or butt.

The proportion of lean was lower and subcutaneous fat higher in male pigs in the picnic, hock, ham, loin and butt than in female pigs (Table 11 a; $P < 0.05$). Intermuscular fat was increased in male pigs in the picnic, ham and loin ($P < 0.01$). The proportion of bone in the loin was reduced in male pigs ($P < 0.01$). Except for the proportion of lean in the butt and the loin, and subcutaneous fat in the loin, there were no treatment by sex interactions on the composition of the primal cuts (Table 11b). The proportion of lean in both the loin and the butt was increased in male pigs fed the flaxseed diet relative to the control or vitamin E supplemented diet; an effect not observed in the female pigs ($P < 0.05$).

The overall proportion of lean, bone, subcutaneous fat, body cavity fat, total intermuscular fat, or total dissectible fat was unaffected by treatment (Table 12a; $P > 0.10$). The proportion of total subcutaneous, body cavity, intermuscular and dissectible fat was higher in male than female pigs ($P < 0.05$). Female pigs had more overall bone, and lean ($P < 0.05$).

Interactions of sex and treatment on the composition of lean cuts are described in Table 12b. Total lean was lower in male pigs fed either the control or flaxseed plus vitamin E treatment diets, an effect not seen in female pigs (treatment by sex; $P = 0.04$). The opposite pattern was observed in in total dissectible and subcutaneous fat; the lowest proportion was seen in pigs fed the flaxseed diets in the male pigs ($P = 0.03$).

There were few effects of treatment on the sensory analysis of the fresh meat (Table 13a). Except for pork flavour intensity which was reduced in the flaxseed fed pigs, (regardless of the addition of vitamin E) there were no effects of treatment on initial or overall tenderness, initial, or sustained juiciness, flavour, or overall palatability ($P < 0.05$).

Flavour descriptors, of the meat, including metallic, off sour, barny, rancid, other or unidentified were not affected by treatment diet ($P > 0.05$). The descriptor "stale" was used at a frequency of 1.66 for the pork from pigs fed the control diet, while not from pigs fed flaxseed or the flaxseed plus vitamin E diets ($P < 0.02$). Similarly, the pork from pigs fed the control diet was described as having a "spongy" texture in more samples than the pigs fed a flaxseed supplemented diet ($P < 0.03$). Cooking time was reduced in the pork from the pigs fed a diet with 5% flaxseed ($P < 0.05$). loss during cooking, however, was unaffected by treatment ($P > 0.10$).

The only gender effects on sensory parameters of the fresh meat were an improvement in overall tenderness in pork from male pigs and a reduced variability (standard deviation) in the flavour intensity measurements (Table 13a; $P < 0.05$).

Treatment effects on the sensory properties of the meat was similar regardless of gender for most of the parameters including initial and overall tenderness, initial and sustained juiciness, flavour intensity and desirability, variability associated with these measurements (standard deviation) and flavour and texture descriptor percentages (Table 13b; sex by treatment interaction, $P > 0.05$). A sex by treatment interaction was observed for cooktime. Meat obtained from female pigs fed a diet with supplemental vitamin E had an increased cooktime, while in the male pigs, an extended cooktime was seen in meat from the control fed pigs (sex by treatment interaction, $P < 0.02$).

Tables 14a,b describe the results of the same set of sensory analysis, but on reheated, rather than on fresh meat. Treatment differences were more pronounced when using reheated meat. Flavour desirability was lower in chops from pigs fed a diet with 5 % added flaxseed, regardless of added vitamin E ($P < 0.05$).

However, off flavour intensity, was reduced in the pork from pigs a diet with flaxseed, but similar to the control when the pigs received flaxseed plus vitamin E ($P < 0.05$). The reduced off flavour intensity in the pork from the flaxseed fed pigs was accompanied by a higher standard deviation ($P < 0.05$). More pork from pigs fed flaxseed was given a flavour description of "other" ($P < 0.05$) and the cooktime required to reheat the chops to 65 C was reduced in the meat from pigs fed flaxseed, with and without added vitamin E ($P < 0.05$).

Taste panel evaluation of the reheated meat identified few differences between pork from male and female pigs (Table 14b). Meat was labeled "off sour" more when it was derived from a female carcass ($P < 0.01$).

Similarly, there were few interactions between sex and treatment on sensory analysis of the reheated meat. Initial juiciness was reduced in pork from male, but not female flaxseed fed pigs (sex by treatment interaction, $P < 0.01$) and meat was labeled as "mushy" when derived from male, but not female pigs, fed a diet containing flaxseed and vitamin E. Initial cookloss weight was higher in meat from male pigs fed a flaxseed containing diet, an effect next seen in meat from female pigs (sex by treatment interaction, $P < 0.05$).

The effect of treatment or sex on the sensory analysis of burgers is shown in Table 15a and the interaction in Table 15b. Initial tenderness and sustained juiciness of the burgers was lowest in the meat from control diet fed animals, and significantly different from meat obtained from pigs fed 5% flaxseed plus vitamin E ($P < 0.05$). Initial juiciness was reduced in meat from pigs fed the control diet relative to the flaxseed fed pigs, regardless of vitamin E ($P < 0.01$). Flavour desirability, overall palatability and off-flavour intensities were highest in burgers from pigs fed the control diet, lowest when the pigs were fed 5 % flaxseed, and intermediate when the pigs were fed the flaxseed diet supplemented with vitamin E ($P < 0.01$). The standard deviation of sensory analysis parameters was unaffected by treatment ($P > 0.05$). Burgers from pigs fed flaxseed had more rancid flavours, and flavour listed as "other" compared to either the control, or the flaxseed plus vitamin E treatments ($P < 0.01$). Burgers with "unidentified" flavours were more likely to come from pigs fed flaxseed plus vitamin E and those labeled as "none" as a flavour descriptor more likely to come from pigs fed the control diet ($P < 0.01$).

A greater proportion of burgers were identified as "typical pork: were derived from pigs fed the control diet, than a diet supplemented with flaxseed plus vitamin E, while the flaxseed treatment was intermediate ($P < 0.01$). Burgers from either the flaxseed or the flaxseed plus vitamin E treatments, were more likely to be labeled as "mushy" ($P < 0.01$).

Except for burgers from male pigs rated higher for initial juiciness ($P < 0.05$) there were no gender effects on the sensory analysis parameters of burgers ($P > 0.05$) and there were no treatment by sex interactions for these paramters (Table 15b; $P > 0.05$).

Table 1. An example of a partial block illustrating the factorial arrangement of treatments.

Block[a]	Treatment[b]	Weight Group[c]	Gender
1	1	Light	M
1	1	Light	M
1	1	Light	F
1	1	Light	F
1	1	Heavy	M
1	1	Heavy	M
1	1	Heavy	F
1	1	Heavy	F

[a]The experiment used 4 blocks, 24 pigs per block

[b]Each block consisted of 3 treatments, 8 pigs per treatment

[c]Weight group refers to an initial weight of either 30 ± 4 or 44 ± kg BW. All animals were on test for 12 wks.

Table 2. Ingredient composition of experimental diets.

Ingredients (%)	Control	5 % flax	5 % flax + Vit E
		Phase 1 30 - 60 kg BW	
Wheat	50.189	30.1793	30.142
Barley	12.8	28.478	28.478
Soybean meal	23	22.9	22.9
Field peas	10	5	5
Linpro[a]	0	10	10
Tallow	0.899	0.45	0.45
Dicalcium phosphate	0.85	0.8	0.8
Limestone	0.8	0.775	0.775
Vitamin mix[b]	0.75	0.75	0.75
Mineral mix[c]	0.075	0.075	0.075
Salt	0.5	0.5	0.5
L-Lysine-HCl	0.085	0.063	0.063
L-Threonine	0.04	0.02	0.02
DL-Methionine	0.01	0.0075	0.0075
Rovimix E-50[d]	0.0022	0.0022	0.04
		Phase 2 60 - 90 kg	
Wheat	48.408	30.367	30.349
Barley	20.8	35.161	35.161
Soybean meal	16.5	15.75	15.75
Field peas	10	5	5
Linpro[a]	0	10	10
Tallow	1	0.5	0.5
Dicalcium phosphate	0.95	0.9	0.9
Limestone	0.8	0.775	0.775
Vitamin mix[b]	0.75	0.75	0.75
Mineral mix[c]	0.075	0.075	0.075
Salt	0.5	0.5	0.5
L-Lysine-Hcl	0.15	0.145	0.145
L-Threonine	0.055	0.045	0.045
DL-Methionine	0.01	0.01	0.01
Rovimix E-50[d]	0.0022	0.0022	0.04
		Phase 3 90 - 120 kg	
Wheat	39.893	26.587	26.549
Barley	32.5	42.727	42.727
Soybean meal	8.7	7.133	7.133
Field peas	15	10	10
Linpro[a]	0	10	10
Tallow	1	0.667	0.667
Dicalcium phosphate	0.5	0.483	0.483
Limestone	0.9	0.883	0.883
Vitamin mix[b]	0.75	0.75	0.75
Mineral mixc	0.104	0.104	0.104
Salt	0.5	0.5	0.5
L-Lysine-Hcl	0.075	0.088	0.088
L-Threonine	0.005	0.005	0.005
DL-Methionine	0	0	0
DG-200 MG Selenium (SE2)	0.075	0.075	0.075
Rovimix E-50[d]	0.0022	0.0022	0.04

[a]Linpro®, 50:50 extruded flaxseed: field pea blend. O & T Farms, Regina, SK

[b]Vitamin premix. Custom formulation, No Vit. E, Co-Op Feeds, Saskatoon, SK Supplied per kg of final feed; Vit. A, 9.2 KIU; Vit. D, 1.2 KIU; Vit K (Menadione), 2.9 mg; thiamine, 4.2 mg; riboflavin, 6.45 mg; pantothenic acid, 24 mg; folic acid, 1.1 mg; niacin, 32.4 mg; pyridoxine, 2.2 mg; thiamine, 4.2 mg; Vit. B_{12}, 0.03 mg; biotin, 0.11 mg; Endox (antioxidant) 75 mg;

[c]Mineral premix. Supplied per kg of final feed (at 0.104 % add rate). Fe, 108 mg; Zn ($ZnSO_4$) 112 mg; Mn ($MnSO_4$) 32 mg; Cu ($CuSO_4$) 12 mg; calcim iodate 1 mg.

[d]Vitamin E premix, DSM Nutritional Products, Ayr. ON. . Contains > 50 % dl α tocopheryl acetate.

Table 3. Nutrient composition of experimental diets, (as is basis)

		Phase 1 30 - 60 kg BW	
Nutrient	Control	5 % flax	5 % flax + Vit E
Dry Matter, %	88.0	88.3	87.3
Crude protein, %	21.3	21.6	22.4
Ether extract, %			
Ca, %	0.78	0.73	0.91
P (total), %	0.68	0.64	0.71
Mg, %	0.19	0.18	0.18
K, %	0.86	0.83	0.84
Na, %	0.24	0.22	0.26
Se, mg/kg[a]	0.49		
Vit E[a]			
		Phase 2 60 - 90 kg	
Dry Matter, %	87.2	87.4	86.3
Crude protein, %	15.6	15.6	15.9
Ether extract, %			
Ca, %	0.66	0.66	0.59
P (total), %	0.48	0.49	0.47
Mg, %	0.16	0.15	0.15
K, %	0.63	0.61	0.62
Na, %	0.24	0.22	0.22
Se, mg/kg[a]	0.50		
Vit E[a]			
		Phase 3 90 - 120 kg	
Dry Matter, %	88.1	87.5	88.0
Crude protein, %	21.8	21.3	22.0
Ether extract, %			
Ca, %	0.06	0.80	0.66
P (total), %	0.57	0.61	0.58
Mg, %	0.18	0.17	0.18
K, %	0.86	0.86	0.90
Na, %	0.21	0.26	0.19
Se, mg/kg[a]	0.50		
Vit E[a]			

[a]Only a subset of diets submitted for analysis.

Table 4. The effect of 5% flaxseed or 5% flaxseed plus 200 IU/kg vitamin E or gender on performance of growing pigs.

	Diet				P-value	Sex			P-value[a]
	Control	Flax	Vit E	SEM	Diet	Male	Female	SEM	Gender
Initial Wt	34.76	35.13	35.51	0.49	0.5630	35.41	34.85	0.40	0.3468
ADG									
Phase 1	1.03	1.04	1.01	0.02	0.5101	1.06	1.00	0.02	0.0152
Phase 2	1.14	1.14	1.12	0.02	0.7272	1.18	1.08	0.02	<0.0001
Phase 3	0.96	0.91	0.95	0.03	0.5558	0.95	0.93	0.03	0.4867
Feed Intake									
Phase 1	2.05	2.06	2.00	0.04	0.4521	2.10	1.97	0.03	0.0027
Phase 2	2.78	2.78	2.72	0.05	0.6101	2.95	2.57	0.04	<0.0001
Phase 3	3.52	3.41	3.49	0.09	0.7005	3.59	3.36	0.07	0.0344
Gain:feed									
Phase 1	0.50	0.51	0.51	0.01	0.9441	0.50	0.51	0.01	0.5554
Phase 2	0.41	0.41	0.42	0.01	0.8480	0.40	0.43	0.01	0.0588
Phase 3	0.28	0.27	0.27	0.01	0.8950	0.27	0.28	0.01	0.2013
Final Wt	113.43	113.25	114.27	1.09	0.7640	116.47	110.77	0.89	<0.0001
Overall ADG	1.04	1.03	1.04	0.01	0.9113	1.07	1.01	0.01	<0.0001
Overall ADF[b]	2.61	2.61	2.60	0.04	0.9906	2.77	2.44	0.03	<0.0001b
Overall FCE	0.40	0.40	0.40	0.01	0.7785	0.39	0.41	0.005	0.0003

[a]Unless indicated otherwise, diet by gender, $P > 0.10$.

[b]Diet by gender, $P = 0.02$.

Table 5. The effect of initial weight group block on performance of growing pigs.

	Initial weight block			
	Heavy	**Light**	**SEM**	**P value**
Initial Wt	39.05	31.27	0.41	<0.0001
ADG				
Phase 1	1.05	1.01	0.02	0.0844
Phase 2	1.16	1.10	0.02	0.0131
Phase 3	0.92	0.96	0.03	0.2376
Feed Intake				
Phase 1	2.06	2.01	0.03	0.2039
Phase 2	2.73	2.78	0.04	0.4427
Phase 3	3.38	3.56	0.07	0.0848
FCE				
Phase 1	0.51	0.50	0.01	0.5155
Phase 2	0.43	0.40	0.01	0.0074
Phase 3	0.27	0.28	0.01	0.6578
Final Wt	118.23	109.06	0.89	<0.0001
Overall ADG	1.05	1.03	0.01	0.2761
Overall ADF b	2.67	2.54	0.03	0.0021
Overall FCE	0.39	0.41	0.01	0.0355

[a]Unless indicated otherwise diet by weight group interaction, P > 0.05.
[b]Diet by weight group, P = 0.01.

Table 6. The effect of 5% flaxseed or 5% flaxseed plus 200 IU/kg vitamin E and initial weight group, or gender, on the performance of growing pigs

	Heavy			**Light**				
	Control	**Flax**	**Vit. E**	**Control**	**Flax**	**Vit. E**	**SEM**	**P value[a]**
Overall ADF	2.81	2.67	2.74	2.75	2.83	2.76	0.04	0.0146
	Male			**Female**				
	Control	**Flax**	**Vit. E**	**Control**	**Flax**	**Vit. E**		
Overall ADF	2.90	2.83	2.93	2.66	2.67	2.57	0.04	0.0355

[a]Interaction of weight group (or gender) by treatment.

Table 7a. The effect of 5% flaxseed or 5% flaxseed plus 200 IU/kg vitamin E or gender on drip loss and carcass parameters of growing swine.

	Diet					Sex			
	Control	**Flax**	**Vit E**	**SEM**	**P value**	**Female**	**Male**	**SEM**	**P value**
Plant weight, kg	109.88	109.74	109.65	1.34	0.9925	107.85[b]	111.67[a]	1.09	**0.0150**
Left side cooler loss, %	2.66	2.57	2.63	0.13	0.4719	2.65	2.59	0.12	0.2812
Right side cooler loss, %	2.64	2.56	2.63	0.17	0.6280	2.66	2.56	0.17	0.1572
Cooler loss, %	2.65	2.56	2.63	0.14	0.4046	2.66	2.57	0.14	0.1157
Commercial hot weight, kg	91.37	91.46	91.16	1.14	0.9823	89.70[b]	92.95[a]	0.93	**0.0156**
Hot dressing, %	83.13	83.36	83.13	0.21	0.6763	83.17	83.25	0.18	0.7559
WHE Equation	61.33	61.24	61.39	0.32	0.9331	62.25[a]	60.39[b]	0.27	**<0.0001**
Estimated Lean Yield, %	62.38	62.28	62.53	0.24	0.7626	63.26[a]	61.53[b]	0.20	**<0.0001**
Lean Yield, %	61.38	62.39	62.05	0.53	0.2138	63.25[a]	60.63[b]	0.48	**<0.0001**
Marbling, NPPC	1.70	1.57	1.53	0.08	0.2462	1.51[b]	1.69[a]	0.07	**0.0375**
Fat Hardness	66.99[a]	56.08[b]	56.61[b]	4.57	**<.0001**	57.51[b]	62.28[a]	4.53	**0.0003**

Table 7b. The effect of 5% flaxseed or 5% flaxseed plus 200 IU/kg vitamin E and gender on drip loss and carcass parameters of growing swine.

	Female			Male				
	Control	**Flax**	**Vit E**	**Control**	**Flax**	**Vit E**	**SEM**	**P value[a]**
Plant weight, kg	107.59	108.31	107.63	112.17	111.17	111.67	1.88	0.8961
Left side cooler loss, %	2.67	2.65	2.64	2.65	2.49	2.62	0.14	0.5929
Right side cooler loss, %	2.67	2.69	2.62	2.61	2.43	2.63	0.18	0.3198
Cooler loss, %	2.67	2.67	2.63	2.63	2.46	2.63	0.15	0.2797
Commercial hot weight, kg	89.36	90.28	89.48	93.37	92.64	92.84	1.61	0.8760
Hot dressing, %	83.00	83.37	83.13	83.25	83.35	83.13	0.31	0.8908
WHE Equation	62.36	61.81	62.58	60.31	60.66	60.19	0.43	0.3055
Estimated Lean Yield, %	63.29	62.82	63.66	61.46	61.74	61.39	0.34	0.2103
Lean Yield, %	62.92	62.90	63.92	59.83	61.89	60.17	0.67	0.0570
Marbling, NPPC	1.59	1.53	1.40	1.80	1.60	1.66	0.11	0.6428
Fat Hardness	63.02	55.13	54.36	70.95	57.02	58.85	4.70	0.1437

[a]Treatment by sex interaction.

Table 8a. The effect of 5% flaxseed or 5% flaxseed plus 200 IU/kg Vitamin E or gender on meat quality parameters .

	Diet					Sex			
	Control	Flax	Vitamin E	SEM	Prob	Female	Male	SEM	Prob
pH and Temperature (°C)									
pH, 45 minutes	6.24	6.23	6.25	0.02	0.7901	6.22	6.26	0.02	0.1751
pH, 48 hours	5.73	5.78	5.78	0.11	0.2342	5.74	5.78	0.11	0.1431
Temp, 45 minutes	40.2	40.0	40.0	0.2	0.3603	40.1	40.0	0.2	0.2990
Temp, 48 hours	1.7	1.8	1.7	0.2	0.6713	1.7	1.8	0.2	0.2726
Subjective Measurements									
Color	3	3	3	0.1	0.3044	3	3	0.1	0.5979
Structure	3	3	3	0.1	0.1769	3	3	0.1	0.3766
Objective Measurements									
L*	51.52	50.21	50.62	0.59	0.1181	50.74	50.82	0.54	0.8767
Chroma	9.67	9.58	9.90	0.23	0.6120	9.87	9.57	0.19	0.2630
Hue	27.62	26.22	26.56	1.45	0.2662	26.62	26.99	1.41	0.6165
Shear, kg	6.55	6.78	6.93	0.29	0.4741	6.95	6.56	0.26	0.1281
Cookloss, $mg.g^{-1}$	172.73	172.56	182.57	4.15	0.1581	181.35^{a}	170.55^{b}	3.39	**0.0268**
Cooktime, $sec.g^{-1}$	5.36	5.58	5.65	0.25	0.6255	5.41	5.65	0.21	0.3471
Driploss, $mg.g^{-1}$	37.75	35.11	38.41	3.23	0.6357	38.18	36.00	2.87	0.4691
Proximate Analysis Lean ($mg.g^{-1}$)									
Moisture	748.35	748.97	748.37	1.46	0.8330	750.04^{a}	747.09^{b}	1.39	**0.0026**
Fat	16.52	16.49	17.18	1.14	0.8238	15.42^{b}	18.04^{a}	1.03	**0.0125**
Protein	232.05	231.44	231.86	0.92	0.7830	231.40	232.17	0.85	0.2967
Proximate Analysis 20% Fat ($mg.g^{-1}$)									
Moisture	628.56	621.57	619.12	4.18	0.0509	626.22	619.94	3.86	0.0535
Fat	182.97	189.11	194.84	7.94	0.3432	180.17^{b}	197.77^{a}	7.24	**0.0087**

Table 8b. The effect of 5% flaxseed or 5% flaxseed plus 200 IU/kg vitamin E and gender on meat quality parameters.

	Female			Male				
	Control	**Flax**	**Vitamin E[a]**	**Control**	**Flax**	**Vitamin E[a]**	**SEM**	**Prob[a]**
pH and Temperature (°C)								
pH, 45 minutes	6.21	6.23	6.24	6.27	6.23	6.26	0.03	0.6179
pH, 48 hours	5.71	5.75	5.77	5.76	5.80	5.78	0.12	0.7320
Temp, 45 minutes	40.2	40.0	40.2	40.2	39.9	39.9	0.2	0.7024
Temp, 48 hours	1.6	1.8	1.6	1.8	1.8	1.8	0.2	0.8186
Subjective Measurements								
Color	3	3	3	3	3	3	0.1	0.4799
Structure	3	3	3	3	3	3	0.1	0.8420
Objective Measurements								
L*	51.82	50.73	49.68	51.21	49.69	51.57	0.75	0.0555
Chroma	10.09	9.69	9.83	9.24	9.48	9.97	0.33	0.3175
Hue	27.97^{a}	27.29^{ab}	24.59^{c}	27.27^{ab}	25.15^{bc}	28.54^{a}	1.59	**0.0030**
Shear, kg	6.88	6.65	7.32	6.22	6.92	6.53	0.36	0.1819
Cookloss, $mg.g^{-1}$	181.75	174.14	188.16	163.71	170.97	176.98	5.87	0.4478
Cooktime, $sec.g^{-1}$	5.24	5.59	5.39	5.48	5.56	5.91	0.34	0.6980
Driploss, $mg.g^{-1}$	41.16	36.96	36.41	34.33	33.25	40.41	4.15	0.3239
Proximate Analysis Lean ($mg.g^{-1}$)								
Moisture	749.65	749.77	750.7	747.05	748.17	746.04	1.68	0.4167
Fat	15.73	15.51	15.03	17.31	17.47	19.33	1.45	0.5082
Protein	231.43	231.37	231.39	232.66	231.5	232.33	1.12	0.8170
Proximate Analysis 20% Fat ($mg.g^{-1}$)								
Moisture	631.25	622.94	624.47	625.86	620.21	613.77	5.02	0.5899
Fat	176.60	181.29	182.62	189.34	196.92	207.06	9.77	0.7528

[a]Treatment by sex interaction.

Table 9a. The effect of 5% flaxseed or 5% flaxseed plus 200 IU/kg vitamin E or gender on the proximate analysis of the ham and loin.

	Diet					Sex			
	Control	**Flax**	**Vit E**	**SEM**	**P value**	**Female**	**Male**	**SEM**	**Prob**
Moisture, mg.g^{-1}									
Ham	747.87	742.48	748.03	4.20	0.5065	748.87	743.37	3.58	0.2170
Loin	732.22	726.62	728.33	2.10	0.0637	732.09[a]	726.03[b]	1.87	**0.0032**
Fat, mg.g^{-1}									
Ham	32.15	31.91	30.48	1.83	0.7679	30.33	32.70	1.52	0.2502
Loin	45.33[b]	50.97[a]	51.02[a]	1.68	**0.0272**	44.64[b]	53.58[a]	1.38	**<.0001**
Protein, mg.g^{-1}									
Ham	216.21	222.17	218.45	3.44	0.4696	217.39	220.49	2.82	0.4381
Loin	218.55	218.29	216.60	0.91	0.2679	219.23[a]	216.40[b]	0.74	**0.0098**

Table 9b. The effect of 5% flaxseed or 5% flaxseed plus 200 IU/kg vitamin E and gender on the proximate analysis of the ham and loin.

	Female			Male				
	Control	**Flax**	**Vit E[a]**	**Control**	**Flax**	**Vit E[a]**	**SEM**	**P value[a]**
Moisture, mg.g^{-1}								
Ham	747.88	748.77	749.97	747.85	736.18	746.09	5.66	0.4937
Loin	734.50	729.54	732.22	729.94	723.70	724.44	2.69	0.7909
Fat, mg.g^{-1}								
Ham	32.98	28.91	29.10	31.32	34.92	31.86	2.54	0.3125
Loin	42.75	45.22	45.96	47.92	56.73	56.08	2.35	0.3671
Protein, mg.g^{-1}								
Ham	215.67	218.73	217.78	216.76	225.61	219.12	4.86	0.7970
Loin	218.79	221.37	217.54	218.32	215.21	215.67	1.28	0.0814

[a]Treatment by sex interaction.

Table 10a. The effect of 5% flaxseed or 5% flaxseed plus 200 IU/kg vitamin E or gender on primal rough weights (% of side weight).

	Diet					Sex			
% of side weight	**Control**	**Flax**	**Vit E**	**SEM**	**P value**	**Female**	**Male**	**SEM**	**P value**
Picnic	10.84	10.64	10.73	0.11	0.4265	10.65	10.83	0.09	0.1496
Hock	2.28	2.27	2.26	0.04	0.9744	2.32[a]	2.22[b]	0.03	**0.0466**
Butt	10.55	10.55	10.36	0.11	0.2518	10.42	10.55	0.09	0.2499
Ham	26.75	26.96	26.71	0.25	0.6098	27.21[a]	26.40[b]	0.23	**0.0004**
Loin	26.36	26.74	26.75	0.26	0.3474	26.5	26.74	0.23	0.3444
Belly	17.31	16.97	17.39	0.16	0.1461	17.09	17.36	0.13	0.1323

[a]Vitamin E treatment diet also contained 5 % flaxseed.

Table 10b. The effect of 5% flaxseed or 5% flaxseed plus 200 IU/kg vitamin E and gender on primal rough weights (% of side weight).

	Female			Male				
% of side weight	**Control**	**Flax**	**Vit E**	**Control**	**Flax**	**Vit E**	**SEM**	**P value[a]**
Picnic	10.79	10.42	10.73	10.88	10.86	10.74	0.16	0.3311
Hock	2.35	2.31	2.29	2.20	2.24	2.24	0.06	0.6100
Butt	10.49	10.35	10.42	10.60	10.74	10.29	0.14	0.1457
Ham	26.98	27.41	27.23	26.51	26.50	26.19	0.32	0.5470
Loin	26.43	26.56	26.51	26.29	26.93	27.00	0.34	0.5448
Belly	17.09[bc]	17.16[abc]	17.02[bc]	17.54[ab]	16.79[c]	17.76[a]	0.23	**0.0413**

[a]Treatment by sex interaction.

Table 11a. The effect of 5% flaxseed or 5% flaxseed plus 200 IU/kg vitamin E or gender on the composition of individual primal cuts.

	Diet					Sex			
g/kg	Control	Flax	Vit E	SEM	P value	Female	Male	SEM	P value
Picnic									
Lean	693.95	708.52	701.49	7.25	0.1084	719.42[a]	683.22[b]	6.67	**<.0001**
Bone	78.61	82.48	82.60	1.43	0.0813	81.85	80.62	1.17	0.4541
Subcutaneous Fat	133.32[a]	119.00[b]	123.57[ab]	6.19	**0.0237**	112.15[b]	138.45[a]	5.80	**<.0001**
Body Cavity Fat	9.65	8.06	9.24	0.51	0.0709	8.86	9.11	0.41	0.6715
Intermuscular Fat	84.51	81.97	83.07	3.11	0.7172	77.75[b]	88.62[a]	2.83	**<.0001**
Hock									
Lean	400.72	401.81	396.46	4.56	0.6187	408.89[a]	390.44[b]	3.91	**0.0002**
Bone	369.13	363.85	369.25	3.87	0.5216	363.60	371.22	3.17	0.0880
Subcutaneous Fat	187.05	191.45	193.58	5.29	0.4673	185.80[b]	195.59[a]	4.81	**0.0285**
Intermuscular Fat	43.25	42.81	40.89	3.17	0.7594	41.66	42.97	2.86	0.6329
Ham									
Lean	692.85	698.37	695.81	6.13	0.7390	709.86[a]	681.49[b]	5.38	**<.0001**
Bone	84.06	83.27	85.79	1.22	0.2306	84.13	84.62	1.05	0.6837
Subcutaneous Fat	186.35	182.15	183.92	5.06	0.7978	173.02[b]	195.25[a]	4.35	**<.0001**
Body Cavity Fat	3.66	3.32	3.55	0.28	0.6491	2.98[b]	4.03[a]	0.24	**0.0010**
Intermuscular Fat	33.07	32.87	30.92	1.27	0.2131	29.99[b]	34.59[a]	1.15	**<.0001**
Loin									
Lean	608.61	626.39	620.00	9.00	0.2299	643.71[a]	592.96[b]	7.90	**<.0001**
Bone	118.78	114.98	117.22	2.69	0.4259	120.83[a]	113.16[b]	2.41	**0.0019**
Subcutaneous Fat	226.30	216.93	219.12	7.85	0.5676	196.79[b]	244.78[a]	6.86	**<.0001**
Body Cavity Fat	10.81	10.02	10.08	0.49	0.3370	9.17[b]	11.44[a]	0.43	**<.0001**
Intermuscular Fat	35.47	31.68	33.53	1.44	0.1733	29.51[b]	37.61[a]	1.18	**<.0001**
Butt									
Lean	653.18	668.35	667.72	6.06	0.1151	688.04[a]	638.12[b]	5.03	**<.0001**
Bone	42.34	40.61	42.29	1.02	0.3877	42.32	41.18	0.83	0.3282
Subcutaneous Fat	206.98	200.68	195.83	5.47	0.2290	186.22[b]	216.10[a]	4.78	**<.0001**
Intermuscular Fat	97.49	90.47	94.18	2.63	0.1646	83.49[b]	104.60[a]	2.14	**<.0001**
Belly, skinned and trimmed	504.44	521.06	515.27	6.46	0.0507	508.20	518.98	5.82	0.0565
Ribs	225.56	219.12	218.71	4.60	0.3039	222.90	219.36	4.12	0.3836

Table 11b. The effect of 5% flaxseed or 5% flaxseed plus 200 IU/kg vitamin E and gender on the composition of individual primal cuts.

	Female			Male				
g/kg	**Control**	**Flax**	**Vit E**	**Control**	**Flax**	**Vit E**	**SEM**	**P value[a]**
Picnic								
Lean	713.76	717.40	727.09	674.13	699.63	675.88	8.77	0.0531
Bone	79.23	83.44	82.87	77.99	81.53	82.33	2.02	0.9437
Subcutaneous Fat	116.73	112.61	107.12	149.91	125.40	140.03	7.26	0.0896
Body Cavity Fat	9.63	7.84	9.11	9.67	8.29	9.36	0.71	0.9571
Intermuscular Fat	80.64	78.72	73.89	88.38	85.23	92.25	3.84	0.1253
Hock								
Lean	413.43	409.60	403.63	388.02	394.01	389.28	6.15	0.5723
Bone	360.23	361.05	369.54	378.03	366.65	368.97	5.49	0.2301
Subcutaneous Fat	183.47	187.82	186.10	190.62	195.08	201.06	6.56	0.7120
Intermuscular Fat	42.87	41.53	40.57	43.63	44.09	41.21	3.99	0.9502
Ham								
Lean	710.21	703.18	716.19	675.48	693.55	675.42	8.00	0.0752
Bone	83.48	82.86	86.04	84.64	83.68	85.55	1.62	0.8459
Subcutaneous Fat	172.75	179.74	166.58	199.94	184.55	201.26	6.80	0.0538
Body Cavity Fat	3.20	2.90	2.85	4.12	3.73	4.24	0.39	0.7315
Intermuscular Fat	30.36	31.32	28.30	35.78	34.43	33.54	1.59	0.6312
Loin								
Lean	638.98^{ab}	636.35^{ab}	655.78^{a}	578.24^{c}	616.42^{b}	584.22^{c}	11.74	**0.0392**
Bone	123.17	117.90	121.42	114.39	112.05	113.03	3.42	0.8624
Subcutaneous Fat	197.33^{d}	206.96^{cd}	186.07^{d}	255.28^{a}	226.90^{bc}	252.17^{ab}	10.28	0.0329
Body Cavity Fat	9.38	8.98	9.14	12.23	11.06	11.03	0.65	0.6930
Intermuscular Fat	31.14	29.80	27.59	39.79	33.56	39.47	2.04	0.1346
Butt								
Lean	683.13^{a}	681.20^{a}	699.79^{a}	623.23^{c}	655.50^{b}	635.65^{bc}	8.45	0.0412
Bone	42.55	39.79	44.62	42.13	41.44	39.95	1.44	0.0855
Subcutaneous Fat	188.95	194.43	175.27	225.00	206.92	216.39	7.17	0.0665
Intermuscular Fat	85.37	84.58	80.54	109.61	96.37	107.82	3.71	0.0883
Belly, skinned and trimmed	501.99	512.40	510.21	506.89	529.73	520.34	8.12	0.6568
Ribs	223.82	220.56	224.33	227.30	217.69	213.08	5.82	0.3370

[a]Treatment by sex interaction.

Table 12a. The effect of 5% flaxseed or 5% flaxseed plus 200 IU/kg vitamin E or gender on the composition of lean cuts (includes loin, ham, butt and picnic, does not include hock).

	Diet					Sex			
g/kg	Control	Flax	Vitamin E	SEM	P value	Female	Male	SEM	P value
Total Lean	656.70	669.06	664.50	7.06	0.3003	684.04[a]	642.80[b]	6.26	**<.0001**
Total Bone	89.68	88.40	90.68	1.11	0.3485	91.03[a]	88.15[b]	0.90	**0.0269**
Total Subcutaneous Fat	196.07	188.59	189.96	5.83	0.5030	174.81[b]	208.27[a]	5.13	**<.0001**
Total Body Cavity Fat	6.61	5.97	6.29	0.23	0.1311	5.66[b]	6.92[a]	0.20	**<.0001**
Total Intermuscular Fat	50.92	47.92	48.59	1.22	0.1842	44.43[b]	53.86[a]	1.00	**<.0001**
Total Dissectible Fat	253.62	242.50	244.85	6.98	0.3600	224.91[b]	269.07[a]	6.12	**<.0001**

Table 12b. The effect of 5% flaxseed or 5% flaxseed plus 200 IU/kg vitamin E and gender on the composition of lean cuts (includes loin, ham, butt and picnic, does not include hock).

	Female			Male				
g/kg	Control	Flax	Vitamin E	Control	Flax	Vitamin E	SEM	P value[a]
Total Lean	680.86[ab]	677.87[ab]	693.39[a]	632.54[c]	660.26[b]	635.61[c]	9.07	**0.0384**
Total Bone	91.26	89.41	92.41	88.11	87.39	88.96	1.56	0.8910
Total Subcutaneous Fat	175.93[d]	182.19[cd]	166.31[d]	216.21[a]	194.99[bc]	213.62[ab]	7.56	**0.0321**
Total Body Cavity Fat	5.95	5.39	5.64	7.28	6.55	6.94	0.33	0.9555
Total Intermuscular Fat	46.01	45.14	42.13	55.84	50.70	55.05	1.72	0.1038
Total Dissectible Fat	227.88[d]	232.72[cd]	214.12[d]	279.36[a]	252.28[bc]	275.57[ab]	9.07	**0.0331**

[a]Treatment by sex interaction.

Table 13a. The effect of 5% flaxseed or 5% flaxseed plus 200 IU/kg vitamin E or gender on sensory analysis of the fresh meat.

	Diet					Sex			
	Control	Flax	Vitamin E	SEM	P value	Female	Male	SEM	P value
Taste Panellist Mean Values									
Initial Tenderness	5.60	5.47	5.71	0.19	0.3777	5.46	5.72	0.17	0.0617
Initial Juiciness	5.28	5.42	5.41	0.15	0.6043	5.33	5.42	0.13	0.4656
Flavour Desirability	5.40	5.25	5.23	0.11	0.2096	5.36	5.23	0.11	0.1299
Pork Flavour Intensity	5.10[a]	4.88[b]	4.87[b]	0.12	**0.0161**	5.00	4.91	0.11	0.1952
Off Flavour Intensity	7.96	7.85	7.89	0.12	0.5992	7.98	7.82	0.11	0.0742
Sustainable Juiciness	5.08	5.20	5.24	0.12	0.4211	5.16	5.19	0.11	0.7865
Overall Tenderness	5.90	5.73	5.96	0.21	0.3567	5.73[b]	5.99[a]	0.20	**0.0491**
Overall Palatability	4.93	4.82	4.92	0.12	0.5822	4.88	4.90	0.11	0.8987
Taste Panellist Standard Deviation									
Initial Tenderness	1.01	1.06	1.11	0.05	0.3491	1.07	1.05	0.04	0.6421
Initial Juiciness	0.97	1.05	0.99	0.09	0.5661	1.00	1.01	0.08	0.9429
Flavour Desirability	0.99	0.99	1.00	0.05	0.9992	1.03	0.96	0.04	0.1671
Pork Flavour Intensity	1.08	1.02	1.07	0.05	0.5800	1.11[a]	1.00[b]	0.04	**0.0250**
Off Flavour Intensity	1.18	1.24	1.23	0.11	0.8138	1.16	1.27	0.10	0.1787
Sustainable Juiciness	0.98	1.04	1.02	0.06	0.5957	0.98	1.05	0.06	0.2161
Overall Tenderness	1.20	1.28	1.26	0.06	0.4633	1.20	1.29	0.05	0.1107
Overall Palatability	1.12	1.05	1.06	0.05	0.5318	1.09	1.06	0.04	0.5642
Flavour Descriptor Percentages									
Metallic	1.07	3.71	1.90	1.24	0.1913	1.87	2.57	1.10	0.5618
Off sour	19.74	28.11	23.14	3.69	0.1766	22.91	24.42	3.25	0.6805
Barny	2.14	1.64	2.68	1.11	0.8067	1.45	2.86	0.92	0.2797
Stale	1.66[a]	0.00[b]	0.00[b]	0.47	**0.0155**	0.56	0.55	0.40	0.9885
Rancid	0.00	0.00	0.00	0.00	1.0000	0.00	0.00	0.00	1.0000
Other	0.49	1.29	0.67	0.96	0.6713	1.50	0.33	0.56	0.1112
Unidentified	26.87	22.70	26.74	3.74	0.5097	26.16	24.70	3.39	0.6628
None	47.68	42.61	44.48	3.52	0.5971	45.47	44.38	2.93	0.7908
Texture Descriptor Percentages									
Typical Pork	78.37	80.44	82.34	2.56	0.5604	80.22	80.54	2.12	0.9156
Mushy	2.29	1.36	2.63	1.21	0.6501	1.45	2.73	1.08	0.2712
Mealy	9.12	8.06	7.23	2.60	0.7968	7.40	8.88	2.36	0.5195
Spongy	2.20[a]	0.44[b]	0.00[b]	0.60	**0.0267**	0.85	0.91	0.50	0.9295
Rubbery	7.97	9.79	7.74	2.17	0.6924	10.12	6.88	1.91	0.1337
Cooking Data									
Cooktime, sec.g-1	7.25[a]	6.51[b]	6.83[ab]	0.24	**0.0410**	6.78	6.95	0.21	0.4755
Cookloss, mg.g-1	231.44	222.04	217.81	8.17	0.1362	227.19	220.34	7.72	0.2256

Table 13b. The effect of 5% flaxseed or 5% flaxseed plus 200 IU/kg vitamin E and gender on sensory analysis of the fresh meat.

	Female			Male				
	Control	Flax	Vit. E	Control	Flax	Vit. E	SEM	P value[a]
Taste Panellist Mean Values								
Initial Tenderness	5.41	5.49	5.48	5.79	5.45	5.93	0.22	0.2937
Initial Juiciness	5.22	5.51	5.25	5.35	5.34	5.58	0.18	0.2607
Flavour Desirability	5.43	5.30	5.36	5.38	5.21	5.11	0.14	0.6140
Pork Flavour Intensity	5.05	4.94	5.01	5.15	4.83	4.74	0.13	0.1140
Off Flavour Intensity	8.01	7.84	8.08	7.90	7.85	7.70	0.14	0.1945
Sustainable Juiciness	5.06	5.27	5.15	5.11	5.13	5.32	0.15	0.4459
Overall Tenderness	5.69	5.74	5.75	6.10	5.72	6.16	0.24	0.3151
Overall Palatability	4.84	4.83	4.98	5.02	4.80	4.87	0.15	0.5000
Taste Panellist Standard Deviation								
Initial Tenderness	1.03	1.04	1.15	0.99	1.08	1.07	0.07	0.6688
Initial Juiciness	0.97	1.04	0.99	0.97	1.05	0.99	0.10	0.9920
Flavour Desirability	1.05	1.00	1.04	0.94	0.99	0.95	0.07	0.6648
Pork Flavour Intensity	1.13	1.11	1.11	1.04	0.93	1.03	0.07	0.6876
Off Flavour Intensity	1.15	1.25	1.09	1.21	1.22	1.38	0.13	0.2452
Sustainable Juiciness	0.98	0.96	1.00	0.98	1.12	1.04	0.08	0.3856
Overall Tenderness	1.11	1.25	1.24	1.28	1.31	1.29	0.08	0.6192
Overall Palatability	1.11	1.06	1.11	1.13	1.04	1.02	0.07	0.6956
Flavour Descriptor Percentages								
Metallic	1.15	3.61	0.87	0.99	3.80	2.93	1.64	0.7237
Off sour	19.88	28.57	20.28	19.61	27.66	26.01	4.93	0.7194
Barny	0.00	2.46	1.90	4.29	0.83	3.45	1.59	0.1781
Stale	1.66	0.00	0.01	1.66	0.01	0.00	0.67	0.9995
Rancid	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.0000
Other	0.97	2.57	0.96	0.02	0.00	0.96	0.92	0.3499
Unidentified	28.18	23.33	26.99	25.56	22.07	26.49	4.78	0.9665
None	47.82	39.47	49.13	47.54	45.75	39.84	5.08	0.3069
Texture Descriptor Percentages								
Typical Pork	77.66	79.17	83.85	79.09	81.71	80.83	3.68	0.7251
Mushy	2.71	0.00	1.65	1.88	2.72	3.60	1.59	0.4206
Mealy	8.53	8.00	5.66	9.72	8.12	8.79	3.31	0.8635
Spongy	1.67	0.89	0.00	2.74	0.00	0.00	0.85	0.5054
Rubbery	9.40	11.94	9.03	6.54	7.64	6.45	2.89	0.9394
Cooking Data								
Cooktime, sec.g-1	6.71[b]	6.44[b]	7.19[ab]	7.79[a]	6.57[b]	6.48[b]	0.32	**0.0126**
Cookloss, mg.g-1	234.43	222.37	224.76	228.46	221.71	210.86	9.57	0.6275

[a]Treatment by sex interaction.

Table 14a. The effect of 5% flaxseed or 5% flaxseed plus 200 IU/kg vitamin E or gender on the sensory analysis of reheated meat.

	Diet					Sex			
	Control	Flax	Vitamin E	SEM	P value	Female	Male	SEM	P value
Taste Panellist Mean Values									
Initial Tenderness	5.12	4.94	5.11	0.22	0.6006	4.99	5.12	0.20	0.4509
Initial Juiciness	3.63	3.50	3.60	0.10	0.6294	3.54	3.61	0.08	0.5260
Flavour Desirability	5.13[a]	4.80[b]	4.97[ab]	0.12	**0.0109**	4.97	4.97	0.11	0.9975
Pork Flavour Intensity	4.93	4.77	4.90	0.12	0.2393	4.82	4.91	0.11	0.2638
Off Flavour Intensity	7.67[a]	7.29[b]	7.54[a]	0.17	**0.0074**	7.51	7.49	0.16	0.8226
Sustainable Juiciness	3.79	3.79	3.75	0.12	0.9039	3.74	3.81	0.11	0.4307
Overall Tenderness	5.32	5.22	5.38	0.22	0.7080	5.20	5.41	0.20	0.1950
Overall Palatability	4.08	3.78	3.85	0.10	0.0576	3.80	4.01	0.09	0.0537
Taste Panellist Standard Deviation									
Initial Tenderness	0.94	1.03	0.90	0.07	0.1364	0.96	0.95	0.06	0.9591
Initial Juiciness	0.99	0.99	1.03	0.06	0.8162	1.01	1.00	0.05	0.8380
Flavour Desirability	1.05	1.10	1.09	0.05	0.6726	1.09	1.07	0.04	0.6641
Pork Flavour Intensity	1.10	1.05	1.16	0.05	0.2029	1.11	1.10	0.04	0.7683
Off Flavour Intensity	1.33[b]	1.56[a]	1.31[b]	0.07	**0.0073**	1.40	1.40	0.06	0.9367
Sustainable Juiciness	1.09	1.06	1.07	0.05	0.9161	1.11	1.04	0.04	0.2185
Overall Tenderness	1.44	1.29	1.36	0.06	0.1712	1.33	1.40	0.05	0.3084
Overall Palatability	1.05	0.89	0.98	0.06	0.1321	0.97	0.98	0.05	0.9142
Flavour Descriptor Percentages									
Metallic	0.96	0.83	0.00	0.56	0.3814	0.83	0.37	0.47	0.4502
Off sour	10.24	9.98	10.12	2.42	0.9956	13.72[a]	6.51[b]	2.14	**0.0019**
Barny	3.84	3.27	3.32	1.32	0.9264	3.37	3.59	1.14	0.8678
Stale	10.40	10.57	6.77	3.25	0.3096	8.53	9.97	3.04	0.5282
Rancid	0.51	1.92	1.51	0.92	0.4317	1.69	0.94	0.80	0.4137
Other	0.43[b]	9.94[a]	2.19[b]	1.71	**<.0001**	3.30	5.08	1.46	0.3253
Unidentified	38.04	35.14	41.49	2.80	0.2770	35.29	41.15	2.29	0.0725
None	35.81	28.31	34.64	4.62	0.1584	33.33	32.51	4.29	0.8094
Texture Descriptor Percentages									
Typical Pork	58.62	58.71	53.47	3.21	0.3561	58.02	55.84	2.73	0.5205
Mushy	0.00	0.81	1.35	0.66	0.1795	0.54	0.90	0.59	0.5462
Mealy	28.66	25.24	31.60	4.10	0.2899	26.48	30.52	3.75	0.2224
Spongy	0.02	1.31	0.90	0.60	0.2559	1.20	0.29	0.50	0.1642
Rubbery	12.77	13.99	12.65	2.61	0.8764	13.82	12.45	2.33	0.5645
Cooking Data									
Initial Cooktime, sec.g-1	7.23	7.20	7.26	0.27	0.9827	7.17	7.29	0.24	0.6422
Initial Cookloss, mg.g-1	230.20	233.99	225.35	5.21	0.4753	235.32	224.37	4.33	0.0618
Reheat Cooktime, sec.g-1	11.65[a]	10.57[b]	10.35[b]	0.40	**0.0186**	10.97	10.75	0.35	0.5786
Reheat Cookloss, mg.g-1	93.49	87.37	82.69	3.40	0.0545	88.69	87.00	2.89	0.6385

Table 14b. The effect of 5% flaxseed or 5% flaxseed plus 200 IU/kg vitamin E and gender on the sensory analysis of the reheated meat.

	Female			Male				
	Control	Flax	Vit. E	Control	Flax	Vit. E	SEM	P value[a]
Taste Panellist Mean Values								
Initial Tenderness	4.99	5.01	4.98	5.25	4.87	5.25	0.26	0.5417
Initial Juiciness	3.43^{abc}	3.77^{ab}	3.41^{bc}	3.82^{a}	3.22^{c}	3.79^{ab}	0.15	**0.0014**
Flavour Desirability	5.12	4.80	4.99	5.14	4.81	4.96	0.14	0.9629
Pork Flavour Intensity	4.90	4.76	4.81	4.95	4.78	4.99	0.13	0.6459
Off Flavour Intensity	7.67	7.25	7.61	7.67	7.32	7.47	0.19	0.6965
Sustainable Juiciness	3.64^{a}	3.93^{a}	3.65^{a}	3.93^{a}	3.66^{a}	3.84^{a}	0.14	0.0319
Overall Tenderness	5.20	5.18	5.24	5.44	5.26	5.52	0.26	0.8640
Overall Palatability	3.96	3.74	3.70	4.20	3.83	3.99	0.14	0.7003
Taste Panellist Standard Deviation								
Initial Tenderness	0.90	1.05	0.93	0.98	1.01	0.87	0.08	0.4902
Initial Juiciness	0.94	1.09	1.01	1.05	0.88	1.06	0.08	0.1251
Flavour Desirability	1.14	1.09	1.05	0.96	1.12	1.13	0.06	0.1009
Pork Flavour Intensity	1.11	1.08	1.15	1.10	1.02	1.17	0.07	0.8375
Off Flavour Intensity	1.36	1.58	1.27	1.30	1.54	1.36	0.09	0.6504
Sustainable Juiciness	1.10	1.16	1.08	1.08	0.97	1.06	0.08	0.4519
Overall Tenderness	1.39	1.24	1.35	1.48	1.34	1.37	0.08	0.8628
Overall Palatability	1.03	0.93	0.94	1.06	0.84	1.02	0.08	0.5369
Flavour Descriptor Percentages								
Metallic	0.82	1.67	0.00	1.10	0.00	0.01	0.77	0.3597
Off sour	14.76	15.10	11.28	5.71	4.86	8.96	3.12	0.3071
Barny	2.89	3.35	3.87	4.79	3.20	2.77	1.75	0.6377
Stale	11.39	7.74	6.46	9.41	13.41	7.08	3.81	0.3757
Rancid	1.07	2.86	1.13	0.00	0.97	1.90	1.21	0.4710
Other	0.85	8.15	0.91	0.01	11.74	3.47	2.33	0.5754
Unidentified	33.13	34.45	38.29	42.94	35.83	44.68	3.97	0.5620
None	35.31	26.67	38.01	36.31	29.95	31.27	5.50	0.4592
Texture Descriptor Percentages								
Typical Pork	58.09	63.02	52.96	59.16	54.39	53.98	4.37	0.4033
Mushy	0.00^{b}	1.56^{ab}	0.07^{b}	0.00^{b}	0.07^{b}	2.64^{a}	0.84	**0.0219**
Mealy	29.20	18.08	32.17	28.13	32.41	31.04	5.01	0.0913
Spongy	0.02	1.79	1.78	0.02	0.83	0.02	0.82	0.5431
Rubbery	12.77	15.55	13.15	12.77	12.44	12.15	3.34	0.8600
Cooking Data								
Initial Cooktime, sec.g-1	7.12	6.95	7.45	7.33	7.46	7.08	0.35	0.3588
Initial Cookloss, mg.g-1	243.79^{a}	227.08^{ab}	235.07^{ab}	216.60^{b}	240.89^{a}	215.62^{b}	7.27	**0.0109**
Reheat Cooktime, sec.g-1	11.63	10.45	10.82	11.67	10.68	9.89	0.53	0.4346
Reheat Cookloss, mg.g-1	94.09	86.72	85.26	92.88	88.01	80.11	4.63	0.7626

[a]Treatment by sex interaction.

Table 15a. The effect of 5% flaxseed or 5% flaxseed plus 200 IU/kg vitamin E or gender on the sensory analysis of burgers.

	Diet					Sex			
	Control	Flax	Vit. E	SEM	P value	Female	Male	SEM	P value
Taste Panellist Mean Values									
Initial Tenderness	7.65[b]	7.73[ab]	7.77[a]	0.05	**0.0163**	7.70	7.73	0.05	0.4795
Initial Juiciness	5.63[b]	5.98[a]	6.09[a]	0.13	**0.0006**	5.79[b]	6.01[a]	0.12	**0.0291**
Flavour Desirability	5.39[a]	4.85[c]	5.13[b]	0.13	**0.0001**	5.19	5.06	0.12	0.1895
Pork Flavour Intensity	5.21[a]	4.87[b]	5.02[b]	0.14	**0.0005**	5.00	5.08	0.14	0.2391
Off Flavour Intensity	7.83[a]	7.08[c]	7.44[b]	0.10	**<.0001**	7.53	7.38	0.08	0.1861
Sustainable Juiciness	5.81[b]	6.06[a]	6.12[a]	0.13	**0.0009**	5.94	6.05	0.13	0.0982
Overall Tenderness	7.67	7.71	7.71	0.06	0.2617	7.70	7.70	0.05	0.9726
Overall Palatability	5.12[a]	4.63[c]	4.86[b]	0.15	**0.0002**	4.90	4.84	0.15	0.5300
Taste Panellist Standard Deviation									
Initial Tenderness	0.61	0.54	0.56	0.06	0.1625	0.56	0.58	0.05	0.6366
Initial Juiciness	0.91	0.84	0.86	0.07	0.5928	0.91	0.82	0.07	0.1327
Flavour Desirability	1.22	1.18	1.21	0.09	0.8887	1.19	1.21	0.08	0.6890
Pork Flavour Intensity	1.06	1.06	1.13	0.05	0.2836	1.10	1.07	0.05	0.5019
Off Flavour Intensity	1.23	1.46	1.39	0.08	0.0582	1.30	1.41	0.08	0.1592
Sustainable Juiciness	0.95	0.94	0.95	0.09	0.9898	0.94	0.96	0.09	0.7881
Overall Tenderness	0.58	0.58	0.57	0.05	0.9577	0.56	0.60	0.04	0.1152
Overall Palatability	1.46	1.30	1.37	0.09	0.1471	1.34	1.42	0.08	0.2019
Flavour Descriptor Percentages									
Metallic	0.48	0.00	0.00	0.27	0.3659	0.32	0.00	0.22	0.3148
Off sour	12.11	7.04	7.74	2.29	0.1203	7.63	10.29	2.02	0.2199
Barny	16.53	17.72	21.49	1.97	0.1837	17.92	19.23	1.61	0.5641
Stale	2.25	4.53	0.88	1.29	0.0533	2.33	2.78	1.13	0.7143
Rancid	-0.04[b]	6.26[a]	1.47[b]	1.23	**0.0001**	1.76	3.36	1.07	0.1883
Other	3.31[b]	15.35[a]	6.49[b]	1.70	**<.0001**	9.21	7.55	1.39	0.3966
Unidentified	22.79[b]	26.91[ab]	33.09[a]	4.25	**0.0170**	28.42	26.77	3.99	0.5699
None	42.70[a]	22.34[b]	28.69[b]	3.12	**<.0001**	32.53	29.95	2.67	0.4268
Texture Descriptor Percentages									
Typical Pork	83.90[a]	78.61[ab]	71.60[b]	2.94	**0.0061**	76.63	79.44	2.52	0.3581
Mushy	7.18[b]	15.28[a]	20.16[a]	2.92	**0.0012**	14.81	13.60	2.57	0.6633
Mealy	8.86	6.13	8.21	1.93	0.4737	8.55	6.92	1.68	0.3927
Spongy	0.00	0.00	0.00	0.00	1.0000	0.00	0.00	0.00	1.0000
Rubbery	0.00	0.00	0.00	0.00	1.0000	0.00	0.00	0.00	1.0000
Cooking Data									
Cookloss, mg.g-1	238.49	232.03	228.07	5.98	0.1609	234.22	231.50	5.55	0.5402

Table 15b. The effect of 5% flaxseed or 5% flaxseed plus 200 IU/kg vitamin E and gender on sensory analysis of burgers.

	Female			Male				
	Control	Flax	Vitamin E[a]	Control	Flax	Vitamin E[a]	SEM	P value[a]
Taste Panellist Mean Values								
Initial Tenderness	7.64	7.73	7.75	7.66	7.73	7.78	0.06	0.9220
Initial Juiciness	5.46	5.96	5.95	5.80	6.00	6.22	0.16	0.4132
Flavour Desirability	5.45	5.01	5.11	5.33	4.70	5.15	0.16	0.3444
Pork Flavour Intensity	5.19	4.88	4.92	5.24	4.86	5.13	0.16	0.3998
Off Flavour Intensity	7.90	7.25	7.42	7.76	6.91	7.46	0.14	0.3801
Sustainable Juiciness	5.77	6.00	6.05	5.85	6.12	6.19	0.14	0.9298
Overall Tenderness	7.64	7.72	7.74	7.70	7.71	7.68	0.06	0.1614
Overall Palatability	5.12	4.75	4.82	5.12	4.51	4.89	0.17	0.3543
Taste Panellist Standard Deviation								
Initial Tenderness	0.61	0.53	0.54	0.62	0.54	0.57	0.06	0.9746
Initial Juiciness	0.95	0.87	0.91	0.86	0.80	0.80	0.09	0.9606
Flavour Desirability	1.23	1.21	1.13	1.20	1.15	1.29	0.10	0.3095
Pork Flavour Intensity	1.09	1.08	1.12	1.03	1.04	1.14	0.06	0.7662
Off Flavour Intensity	1.15	1.40	1.36	1.31	1.51	1.41	0.11	0.8595
Sustainable Juiciness	0.93	0.95	0.94	0.98	0.94	0.95	0.11	0.8878
Overall Tenderness	0.56	0.59	0.52	0.59	0.58	0.63	0.05	0.1929
Overall Palatability	1.49	1.27	1.24	1.42	1.33	1.50	0.10	0.1160
Flavour Descriptor Percentages								
Metallic	0.95	0.00	0.00	0.00	0.00	0.00	0.39	0.3659
Off sour	11.45	5.92	5.54	12.76	8.16	9.95	2.96	0.8355
Barny	14.88	16.74	22.14	18.17	18.69	20.83	2.79	0.6982
Stale	3.56	3.50	0.00	0.94	5.56	1.83	1.68	0.2153
Rancid	0.00	4.28	1.05	0.00	8.23	1.89	1.62	0.3699
Other	3.45	15.74	8.45	3.17	14.96	4.52	2.40	0.7118
Unidentified	21.20	27.31	36.74	24.37	26.50	29.44	4.94	0.3352
None	44.67	26.53	26.40	40.74	18.15	30.98	4.21	0.2575
Texture Descriptor Percentages								
Typical Pork	84.93	76.34	68.61	82.87	80.87	74.58	3.98	0.5222
Mushy	6.11	17.97	20.37	8.25	12.59	19.96	3.80	0.5315
Mealy	8.90	5.69	11.06	8.82	6.57	5.36	2.55	0.3202
Spongy	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.0000
Rubbery	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.0000
Cooking Data								
Cookloss, mg.g-1	239.23	234.21	229.22	237.74	229.84	226.92	7.12	0.9628

[a]Treatment by sex interaction.

References:

Association of Official Analytical Chemists. 1995. Method 960.39. Fat (Crude) or Ether Extract in Meat Final Action. 1995. OAOC. 39:2.

Association of Official Analytical Chemists. 1995. Method 992.15 Crude Protein in Meat and Meat Products Including Pet Foods. Combustion Method. Final Action 1992. or Ether Extract in Meat Final Action. OAOC. 39:6-7.

ASTM Standards. 2008. D2240-05 Test Method for Rubber Property\Durometer Hardness, In ASTM Volume 9.01 Rubber, Natural and Synthetic - General Test Methods, ASTM International, West Conshohocken, PA, DOI: 10.1520/D2240-05, www.astm.org

Agriculture Canada. 1984. Pork Quality – A guide to understanding colour and structure of pork muscles. Agriculture Canada Pub. 5180/B, Ottowa, ON, Can.

Canadian Council on Animal Care. 1993. Guide to the care and use of experimental animals. Vol. 1, 2nd ed. E.D. Olfert, B.M. Cross, A.A. McWilliam, eds CCAC, Ottowa, ON.

Htoo, J.K., Meng, X., Patience, J.F., Dugan, M.E.R. and Zijlstra, R.T. 2008. Effects of coextrusion of flaxseed and field pea on the digestibility of energy, ether extract, fatty acids, protein, and amino acids in grower-finisher pigs. J. Anim. Sci. 86:2942-2951.

Larmond, E. 1977. Laboratory methods for sensory evaluation of foods. Agriculture Canada, Ottowa, ON. Publ.1637.

Martin, A.H., Fredeen, H.T., Weiss, G.M., Fortin, A. and Sim, D. 1981. Yield of trimmed pork product in relation to weight and backfat thickness of the carcass. Can. J. Anim. Sci. 61:299-310.

SAS Institute Inc. 2003. SAS User's guide: Statistics